NOVEMBER 2011

Tunnels & tunnelling INTERNATIONAL

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China

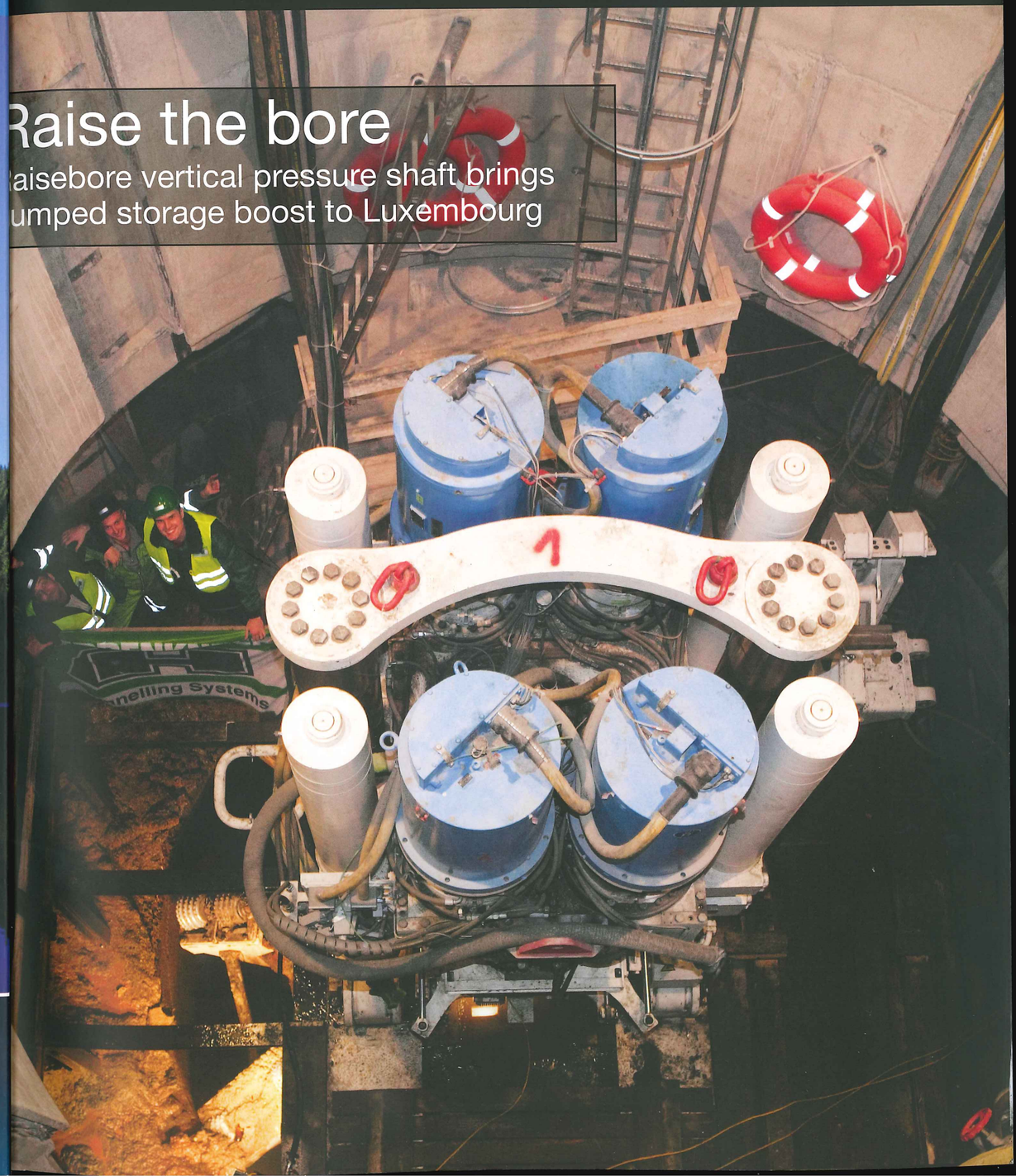
T&TI digs into a world without recession and finds what it means to tunnel China

Hyperbaric intervention

How experts around the world are making compressed air, gas and diving work in tunnels less hazardous and more healthy

Raise the bore

aisebore vertical pressure shaft brings umped storage boost to Luxembourg



SHORTER WAYS IN THE SEA PORT OF ANTWERP.

The sea port of Antwerp is located on both sides of the River Schelde. Two railway tunnels with an interior diameter of 7.3 meters are being built to help better cope with growing cargo volumes between the left riverside and the right – where the Antwerp Station North is located. The shuttle service, provided by 100 trains daily, will save 22 kilometers of transport route as well as the corresponding operating costs.

The "Liefkenshoek Rail Link Project" is one of the largest infrastructure projects ever realized in Belgium. A real challenge for the construction specialists of the THV Locobouw joint venture were the tunnelling operations for the two parallel tubes beneath the canal dock, where the overburden amounts to a mere 1.1 meters. Yet, the passage for large ships had to be kept free at all times, which means that a certain water level had to be maintained in the dock. Therefore, the silty soil in the tunnel area was replaced with mortar and then covered with a two-meter thick reinforced concrete plate. This served as an anchor protection and as an additional weight, allowing passage of the TBM.

The two Herrenknecht Mixshields S-533 and S-532 (Ø 8,390mm) safely and rapidly excavated the two tunnel tubes beneath the port. After 6 kilometers of tunnelling respectively and weekly top performances of up to 250 meters, their arrival in the target shaft was celebrated in May and June 2011.

LIEFKENSHOEK | BELGIUM

PROJECT DATA	CONTRACTOR
S-532, S-533, 2x Mixshields Diameter: 8,390mm Cutterhead power: 1,100kW Tunnel length: 11,942m Geology: sand, boomse klei, limestone	MBG, CEI-De Meyer nv, Vinci Construction Grands Projets, Wayss & Freytag AG

Supporter of:
redr uk

comment

Bring on the boom

The world's seven billionth person drew her first breath last month. According to the United Nations some 80 billion people have walked on the earth before her, and more than seven billion are alive today. Child rights group Plan International named the seven billionth as Indian-born Nargis. She is one of 51 babies to be born every minute in India and one of 267 babies born every minute worldwide.

The wider press has had its usual fun hypothesising the end of the world due to over population. But a sane voice has floated above the rest and that is of the logical thinker asking what action needs to be taken to manage this rapidly expanding population.

And this is where we can cash in.

The construction industry is tightly linked to population, its growth and its movement. And as the world becomes more congested there becomes an increasing case – as can be seen in the world's mega cities – to go underground.

Over the next decade the world's population is projected to grow by 10 per cent to 7.7 billion. The construction industry is predicted to grow by 67 per cent over the same period, from USD 7.2tn to USD 12tn according to Price Waterhouse Coopers' forecast report Global Construction 2020.

It may not surprise many that the countries with the fastest growing populations, India and China, also have the fastest growing construction markets. Of the USD 4.8tn growth predicted for the global construction market, India and China account for 38 per cent of this. China, which became the world's largest construction market in 2010 will remain so over the coming decade. The US will hold onto second position as populations expand – with its own population growth aided by immigration. By 2018 India will be the world's third largest construction market.

While India is seeing staggering population growth, especially in its cities as the country urbanises, it will take some time for it to reach the dizzy heights of China. Come 2020 its construction market will still only be a third of the size of China's.

Unfortunately, the loser in the population boom is Western Europe. With its slow increase in population, bankrupt economies and governments, Western Europe has few positive drivers. Over the next decade the UK construction market can expect some 10 per cent growth compared to 135 per cent in Asian markets.

But tunnelling is an international business and experience counts. The special report on China this month (see page 29) shows that the country is running out of simple places to build tunnels and is starting to lean on the expertise of the West to bring the projects to fruition.

Despite fears of resource shortages and other apocalyptic media spin, growth is good for business. The eighth billionth baby will be born in 2025 and will bring with him or her a reliable need for building.

Jon Young

contents

On the cover:
The Vianden pumped storage project in Luxembourg gets a new vertical pressure shaft (page 22)

OSHA fines Southland

USA

The Occupational Safety and Health Administration (OSHA), part of the U.S. Department of Labor, cited Texas-based Southland Contracting last month for seven violations of workplace safety standards after one of its employees was killed at the Eastside Water Supply Project in Webster, New York.

On April 11, Southland employees were tunnelling the raw water intake tunnel when a fuse blew cutting power to the tunnel lighting circuits.

In the darkness, an employee who was operating a locomotive sustained a fatal head injury when he struck a conveyor on the TBM. OSHA found that the locomotive lacked bumper blocks to stop it as it approached the conveyor. It was pushing an unattached flat car, and it had not been inspected for modifications and repairs.

OSHA reported there was no effective means by which the workers in the tunnel could notify the locomotive operator of problems while he was in transit.

The lighting failed after welding equipment was plugged into branch circuits meant only for temporary lighting. The site had not been inspected by a competent person prior to the work beginning.

These conditions resulted in citations for six serious violations.

"An unfortunate and unnecessary confluence of conditions placed the workers in the tunnel at risk of being struck, crushed or caught in and between the locomotive and the tunnel boring machine," said Arthur Dube, OSHA's area director for western New York. "An inspection by a person with the knowledge to identify and the authority to eliminate these hazards could have prevented this worker's death."

One repeat violation was cited for failing to instruct workers in the recognition and avoidance of "struck-by, caught-in and crushing" hazards associated with tunnel boring and locomotive equipment. According to OSHA a similar hazard was cited at Southland's Batesville, Arkansas, work site in 2010.

Southland Contracting faces a total of USD 55,440 in proposed penalties. The company has 15 business days from receipt of its citations and proposed penalties to comply or contest the findings.

Awards judging kicks off

GLOBAL

Judges of the 2011 T&T Awards were due to meet this month in offices in London and Hong Kong to begin selecting winners for the 10 hotly contested categories. Some 50 entrants submitted projects to the judges who will now nominate a winner and highly commended for each award.

The panel is chaired by BTS chair Bob Ibell and includes Roger Bridge of Balfour Beatty, David Hindle of OTB Engineering, and Bob Frew and John Endicott both of Aecom.

The winners will be announced in a special awards supplement to be published with the December issue of *T&TI*.

Judges for the 2011 Photo Competition were also due to meet this month to sort through the hundreds of images of projects sent in by tunnellers.

Capital breaks ground on Blue Plains tunnel

USA

The District of Columbia Water and Sewer Authority (DC Water) broke ground last month on the USD 2.6bn Clean Rivers project, which will construct two tunnels to store the combined sewage during rain events.

The 23ft (7m) diameter Blue Plains tunnel will be excavated in depths more than 100ft (30.5m) in soft ground as it extends from Blue Plains, along the coast of the Potomac River, crossing under the Anacostia River to RFK Stadium.

A USD 330.5M contract was awarded in spring to a joint venture of Traylor Brothers-Skanska-JayDee (TSJD) for design and construction of the 23,600ft (7.2km) long tunnel. Tunnelling will begin in 2013. Ground investigation revealed the presence of adhesive clay. The cutterhead has been designed to condition and process this material effectively and a camera system will enable inspection of the muck.

"Our design-build contractor, TSJD, has been progressing final designs on this project since issuance of the Notice-To-Proceed on 5 May, 2011," said a DC Water spokesman. "TSJD is currently preparing the site at the Blue Plains Advanced Wastewater Treatment Plant for construction of the slurry diaphragm walls to support both the 60ft screening shaft and 132ft dewatering shaft, scheduled to begin in early December 2011.

"These two shafts are arranged in a figure-eight configuration. After the slurry walls are complete, the interior of the shafts will be excavated then lined with cast-in-place concrete. The groundbreaking ceremony was held at the location of the shafts."

Bay State Precast was chosen to begin fabrication of tunnel liner segments in spring 2012. Approximately 4,000 rings, 6ft (1.83m) each in length, will be manufactured. The plant is located in Maryland 20 miles (32km) away from the project.

CSOs in the area dump 2.5bn gallons (11.4bn litres) of combined sewage into the Anacostia and Potomac Rivers and Rock Creek in an average year.

News in brief

Czech contractor's hydro boost for Vietnam
Czech contractor Skex last month secured a CZK 17.8bn (USD 1bn) contract to build three hydro power plants in Vietnam. Skex signed a binding memorandum with Vietnamese energy firm DLHL and will negotiate deadlines and procedures. The contract will be signed in 2012.

Bangalore launched
The first line of the Bangalore Metro from MG Road station in the city centre to Baiyappanahalli Station in the eastern suburb opened last month. The stretch is part of the 42.3km first phase of the metro rail project being carried out at a cost of INR 116bn (USD 2.2bn), comprised of two corridors.

EIB to fund Finnish refurb
The European Investment Bank will grant USD 350.3M for upgrade work to the Helsinki metro, which will include station renovation. The project will run until 2016. Earlier in 2011 the bank extended a USD 630M dollar loan for the westward extension to Espoo.

World at a glance

A round up of project milestones and challenges

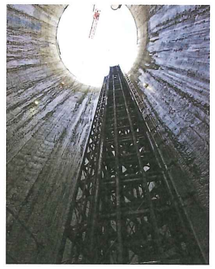
TORONTO, CANADA

A construction worker died at the York University subway station work site last month in Toronto, crushed by a piece of heavy equipment. Police have not yet released the worker's name, nor the name of the construction company that employed the victim. A drilling rig tipped over crushing the construction worker to death and injuring five other workers.

The rig, used to bore holes in the ground, apparently tipped over onto two other pieces of machinery, a backhoe and front-end loader, killing a 25-year-old worker in the cab of one of those vehicles, said a report from Toronto Transit.

Medical personnel rushed five other workers who suffered injuries, ranging from major to minor to Sunnybrook Hospital. Officials continue to investigate the incident. The station is part of the Toronto-York Spadina Subway Extension.

LONDON, GREAT BRITAIN



A contracting JV of Morgan Sindall, Vinci Construction Grands Projets and Bachy Soletanche has completed the first of three shafts at Beckton in east London for the construction of Thames Water's Lee Tunnel sewerage project.

The shaft is 20m in diameter and 75m deep. Recent work on it included the installation of a 4.5m-thick, domed base slab. The next step is to form the final concrete lining by slip-forming.

The project, valued at GBP 635M (USD 994M), is the largest awarded in the UK water services industry since its privatisation in 1989.

The 7km (4.3-mile) long Lee Tunnel itself will be 7m in diameter, run up to 75m deep, and will carry flow to the Beckton water treatment works, which will be expanded by 60 per cent in capacity to deal with the flow.

MIAMI, USA

Florida's Department of Environmental Protection last month announced that it has decided to approve the final permit for the USD 1bn Port of Miami tunnel project. This permit will allow the 13-diameter TBM to begin boring as early as November.

The Herrenknecht TBM arrived in Miami this summer. The project will consist of two tunnel drives that connect Watson Island and Port of Miami, for a length of 3,900ft (1,189m). The agency also signed off on depositing spoils on Virginia Key for a restoration project, as long as environmental officials are able to certify the soil is clean.

SANTIAGO, CHILE

Vinci group has begun the first excavation in its major tunnelling contract as part of the expansion of the El Teniente copper mine in Chile for the national mining corporation Codelco, the world's largest copper producer. The USD 400M contract, which Vinci won in September, is split 60:40 between Vinci Construction Grands Projets and Vinci subsidiary Soletanche Bachy. The work will ensure continued production at the mine for another 60 years. There will be two interconnected tunnels 9km long with an average sectional area of 65sqm.

Initially two Robodrill drilling jumbos were employed in drill and blast excavation in the head, but this is due to rise to a total of 12 excavation rigs and at least one Montabert 108 dedicated rock bolting rig. Half of the drill-and-blast rigs on order are comuterised Robofore three-boom units, and the others are manual Pantofore twin-boomers.

OSMANCIK, TURKEY

A 10m diameter Robbins double shield arrived on site at the Kargi hydropower project in Turkey last month. As *T&TI* went to press it had not been assembled for Turkish contractor Gulermak. The tunnel length will be 11.6km long with a 9.8m diameter through 80 per cent volcanic rock with marble, limestone, ophiolites and sedimentary rock. The plant on the 'Red River' will be built near the town of Osmancik and will have an installed capacity of approximately 102MW.

JAMMU AND KASHMIR, INDIA

Hindustan Construction Company (HCC) has smashed through to daylight on the Pir Panjal railway project. The 10.96km bore, part of the Udhampur to Srinagar to Baramulla rail link, became India's longest and Asia's second longest transportation tunnel at breakthrough last month. "NATM was selected to deal with the variable geology," said a HCC spokesman. "Eight different types of geological strata were found. This was the first large-scale use of NATM in India."

The tunnel was excavated to a width of 8.41m and a height of 7.39m. The HCC spokesman added that the project saw the use of road headers adopted for the first time in India. The alignment runs through the Pir Panjal Mountains in the north of the country.

BURANG COUNTY, CHINA

China's state television network, China Central Television (CCTV), and state news network Xinhua announced last Thursday that works have begun to collect data necessary for the sixth Earth Probe Program. Burang County in Tibet was chosen to host the Earth Probe Program, a core sampling experiment.

CCTV reported that the drilling experiment for the Earth Probe Program has a depth limitation of approximately 10km. This is a relatively shallow point. In order to explore deeper under the earth, explosion experiments have been arranged. Scientists will track and record explosion-induced seismic waves as they are reflected by the various geological layers. This enables analysis of the deep structure of the earth. Lu Zhanwu of the Chinese Academy of Geological Sciences said, "We are now doing experiments to get an in-depth understanding of the structure of the earth under the thick crust of the Tibetan Plateau."

CCTV reported that ten 30m-deep wells have already been drilled with up to a tonne of explosives placed inside at each experimental site. The project team hopes to collect data of the earth down to a depth of 200km. The Earth Probe Program will examine the relationship between tectonic activity and pressure release in the form of earthquakes and volcanos, with a view to forecasting disasters more accurately.

TOKYO, JAPAN

Hitachi Zosen's 'combined circle shape' EPBM passed its acceptance test last month. The 6.8m high, 5.7m wide machine will excavate the Kotakemukai Station to Senkawa Station connecting line on the Yurakucho Line of the Tokyo Metro in Japan. "The TBM will arrive at the jobsite in the middle of November," said a Hitachi Zosen spokesman.

Manager of Hitachi Zosen's engineering department Joji Satoh told *T&TI* that the unusual oval shape was designed to keep the TBM entirely beneath the road and away from privately owned land, as well as minimising excavated soil and maximising distance from other underground infrastructure. Satoh explained, "Combined circle shape means a non-circular shape where the outer shape consists of a circular arc (three curve radius). Spoke length adjusts during excavation to fit the width of the TBM [due to the oval shape]. During a straight-line excavation, copy cutters extend and retract to match the outer shape of the cutter head. When excavating a curve, copy cutters extend further."

SINGAPORE

Yongnam Holdings was awarded contracts to supply temporary steel strutting, sheetpile and decking works for the Kaki Bukit and Kallang Bahru stations on Downtown Line Three (DTL3).

The local steel and civil contractor was awarded three contracts worth a total SGD 30.4M (USD 24M). Contracts 929 and 932A were awarded for Kaki Bukit and Kallang Bahru stations The third contract covered basement works on the Victoria Theatre and Concert Hall. The main contractor on the DTL works packages is China State Construction Engineering Corporation. Work will conclude in 2014.

HONG KONG, CHINA

TBM excavation has been launched on the Sai Ying Pun to Sheung Wan tunnels. The majority of tunnelling for the West Island Line project is drill and blast due to mixed ground. This began in 2009.

Client MTR announced last month that the 6.5m Herrenknecht TBM, named Xi Shi began boring on 30 September. It will begin boring the 592m uptrack tunnel to Sheung Wan, at which point it will be dismantled and brought back to the Sai Woo Lane launch shaft.

A new cutter head will be installed and then construction of the 217m downtrack tunnel will begin.

The West Island Line will open for service in 2014.

ADB signs Hanoi metro loan

VIETNAM

The Asian Development Bank (ADB) kick started the Hanoi Metro Line Three project last month when it signed a USD 293M loan with Hanoi People's Committee. Some 3.6km of Line Three will be run in tunnels with the remaining 8.9km run on elevated track.

ADB country director for Vietnam Tomoyuki Kimura said, "The metro rail project will support efforts of Hanoi's authorities to solve traffic congestion more efficiently and substantially reduce green house gas emissions, ensuring the capital's sustainable socioeconomic development."

The Line Three project, which has also received funding from the French government and the European Investment Bank should be completed by 2015. Kimura said that the ADB saw a dependence on private vehicles, with many families owning three or four motorcycles. Projections have been made that show a switchover to cars as incomes in Vietnam increase, which would worsen the congestion.

Zed Tunnel Guidance targeted for Queen's Award for enterprise

GREAT BRITAIN

Prince Edward Duke of Kent granted Zed Tunnel Guidance with a Queen's Award for Enterprise in the international trade category.

Presented at a ceremony last month, the cut glass commemorative rose bowl recognised Zed Tunnel's value in the global market, based on a combination of the growth and proportion of exports from a total value of its trade.

The Duke of Kent remarked that Zed's team of seven was possibly the smallest to receive a Queen's Award, although he added that this made the recognition more impressive. The Duke was then presented, Lord Lieutenant and Royal Clergy in tow, to the assembled guests including foreign clients, the Zed team and local councillors.

Speaking some days prior to the event, Prince Phillip, Duke of Edinburgh said, "The Queen's Awards were initiated to draw attention to the most successful enterprises; to bring to public notice those enterprises which have succeeded in world markets, and which have made a significant contribution to our national prosperity."

Left: The Duke of Kent presenting Zed director Mick Lowe with an award scroll

Murphy bags London cable contract

GREAT BRITAIN

J Murphy & Sons was awarded a GBP 10M (USD 16M) contract for partial design, construction and project management of an electricity cable tunnel in late September. The 1.3km, 2.44m-diameter bore will run from Brentfield Park to Willesden in northwest London, UK. Preliminary works began on 10 October and the project will finish in August 2013.

A Lovat TBM will excavate the project. Lining will be largely wedge block, with bolted wedge block used in areas of existing infrastructure. A Murphy spokesman said, "One critical element is towards the end of the track in Willesden, where the tunnel will cross 200m of rail track before it reaches the substation. Apart from that this project seems relatively straightforward as London Clay is obviously ideal tunnelling material."

Murphy will also construct three shafts and 143m of shallow tunnel. The company will handle the installation of ventilation equipment and cable support brackets. Four 132kV phase circuits will be carried through the tunnel upon completion.

Murphy tunnelling director Darren Ramsay said, "We are very proud to continue our relationship with UK Power Networks on this contract. We will be utilising our in-house resources and experience to deliver the works, including secant piling for one of the shafts."

News in brief

Thu Thiem Tunnel opens in Ho Chi Minh City, Vietnam
The six lane Thu Thiem Tunnel connecting Districts One and Two in Ho Chi Minh, Vietnam, will open to traffic in November. The 1.49km tunnel passes under the Sai Gon River. It has two middle lanes for cars and buses and one side lane for motorbikes from 6am to 9pm, and for heavy lorries for the rest of the day. The VND 13.4tn (USD 642M) tunnel is part of Ho Chi Minh City's East-West highway.

Lunar tunnels excite Russian space veterans
The discovery of volcanic tunnels on the moon could provide a natural shelter for the first lunar colony, Russian cosmonauts and scientists said last month. Researchers have suspected the moon's volcanic past left an underground network of lava tubes as its legacy, and 2008 images from Japan's Kaguya spacecraft showed a possible way down through a metre deep hole.

Auckland tunnel walk shows public interest
Bookings for a scheduled walk through Victoria Park Tunnel in Auckland, New Zealand, last month reached the safety capacity well in advance. Officials said the community support for the project made the challenging 450m engineering feat 'a whole lot easier'.

University protects students with tunnel
Liberty University in Lynchburg, Virginia, USA, celebrated the end of construction of its new pedestrian tunnel last month. The approximately 60m-long, 3.7m-diameter tunnel was part of a USD 120M upgrade to the campus. The tunnel provides a safe road crossing.

NATM safety in soft ground questioned

GLOBAL

Nearly one in three tunnellers think NATM, or sprayed concrete lining (SCL) is dangerous in soft ground. Industry leaders have been quick to defend NATM arguing that the method is safe if undertaken by an experience team.

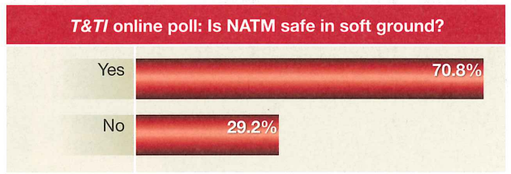
In a *T&T* online opinion poll conducted last month respondents voted 70.8 percent in support of soft ground NATM tunnelling and 29.2 per cent against.

Immediate past president of the International Tunnelling Association and Halcrow tunnelling director Martin Knights said, "NATM is safe in most ground types providing that qualified expertise is involved in the planning, design and construction."

NATM has had a chequered past with public failures such as the 1994 collapse on the Heathrow Express tunnels in London, Great Britain, damaging its reputation for use in soft ground.

Colin Eddie, managing director of Morgan Sindall's Underground Professional Services said, "Successful SCL construction is clearly dependent upon the avoidance of human error," - a phrase taken from the UK Health and Safety Executive report into the Heathrow Express collapse.

He added, "Provided a holistic approach is adopted for the design and construction of the works, there is no reason why a SCL tunnel cannot be safely executed. It is vital however that experienced SCL engineers are responsible for the production of the detailed design and for the safe implementation on site."



Knights said that, "Driving a four by four vehicle on difficult terrain was safe if the driver was experienced and the four by four was in good condition. The same is true for NATM."

Eddie added, "Appropriate monitoring, inspection and test regimes are also essential to ensure that the structure performs as predicted and remains safe and stable at all stages of construction.

"The final essential component is the experience and competence of the workforce. Only personnel who have been appropriately trained and accredited should be given construction responsibilities. It is also important that all the construction personnel are properly briefed on the safety critical elements of the design and that appropriate pre-planned contingency measures are available to react to any unforeseen events."

Nordic nuclear cooperation deal set in stone

SCANDINAVIA

Finnish nuclear disposal research organisation Posiva and Swedish nuclear management company SKB last month signed a three-year cooperation contract for the research and development of nuclear fuel final disposal. Posiva president Reijo Sundell said, "Several years of cooperation between Posiva and SKB have been a great advantage for both parties and as the companies are now proceeding to the construction stage of the final disposal facilities, it is more than well-justified to continue."

SKB managing director Claes Thegerstrom added, "The joint development of the final disposal technology means that the resources of the companies are utilised effectively and the outcome is better than when operating alone."

SKB submitted a licence application in spring to construct a final disposal facility in Forsmark, Sweden, with an encapsulation plant in Oskarshamn. A decision will be made in 2014 with possible construction to follow in 2025. Posiva has been constructing its Onkalo facility since 2004, which reached its final disposal depth last year. The firm will submit a licence application for the final disposal facility itself next year, with actual disposal scheduled to begin in 2020.

Gaddafi taken from safety of tunnels

LIBYA

Colonel Muammar Gaddafi was dragged from his last hiding place – a small drainage tunnel – and killed last month following half a year of violence during the Libyan uprising. Graffiti was scrawled around the mouth of the storm water drain that proclaimed: 'this is the place of Gaddafi, the rat'. The twin drainage tunnels were less than 1m in diameter and less than 15m in length.

Located in the dictator's birthplace, Sirte, the drainage tunnel was a small part of extensive projects implemented by Gaddafi to upgrade his home village to a city. The use of underground space was of special interest to Gaddafi. It was thought that the extensive network of escape tunnels beneath Libya's capital Tripoli would permit the dictator to elude capture.

Better known was the USD 24bn Great Manmade River project. The south to north irrigation project was the largest in the world at the time of construction. It runs for 2,820km with a 4m diameter. In places it is up to 180m deep.

As *T&TI* went to press, it was unknown if the new government would turn to tunnelling with the same alacrity as Gaddafi.

News in brief

'Worldly' Dave Fisher remembered by colleagues
Field service superintendent Dave Fisher passed away on 21 September 2011 at the age of 65. "When he was at a tunnel, you didn't ever get a phone call; he was just that good," said Lok Home, Robbins president. "Dave was one of those rare people you find in life. He was worldly and well-read. He took the time to learn the history and culture of every area that he worked in." Fisher was a native of Washington, USA. He is survived by three brothers, his many nieces and nephews.

Crossrail academy opens its doors to the industry
Great Britain's London Crossrail project has launched its Tunnelling and Underground Construction Academy (TUCA) with the first wave of students. The training courses include the Tunnel Safety Card.

Jacobs' new associates

USA

San Francisco based-Jacobs Associates raised three of its staff to associate level and three to lead associate level. Mike McKenna, Yiming Sun and Sam Swartz were made lead associates. Renee Leslie, Isabelle Pawlik and Rick Vincent were made associates.

McKenna has most recently served as the Jacobs Associates project manager on the Los Angeles Department of Water and Power's Silver Lake Bypass Tunnel project and River Supply Conduit Lower Reach Unit One A project, US.

Sun has most recently worked on providing preliminary design and analysis on the Ottawa Light Rail Project in Ottawa, Canada.

Swartz has most recently worked on providing design support during construction for the University Link Light Rail Project in Seattle, US, and preliminary design support, also on the Ottawa Light Rail Project.

Leslie has most recently served as project manager on New York City's Metropolitan Transportation Authority (MTA) 'Independent Engineering Consulting Services' contract to oversee MTA tunnelling projects in New York, US.

Pawlik served as project engineer and lead tunnel designer on the Bay Tunnel project in California, US and most recently has provided engineering support during construction of the same.

Vincent most recently served as program management structural lead for the Anacostia River Tunnel project in Washington DC, US.

As *T&TI* went to press, William Gates became the latest senior associate to join Jacobs Associates, coming one week after the main throng.

Gates, a retired Green Beret, brought expertise in geotechnical engineering, blasting and hydrogeology and worked in the field for 44 years.

He specialises in fracture analysis, flow and mechanics.

Gates was most recently lead rock engineer on Seattle City Light's Boundary Dam Rockfall Mitigation project in Metaline, Washington, US.

News in brief

Trio of Ottawa light rail tender finalists announced
Three firms have been selected to compete for the construction, finance and operation of the USD 2.1bn Ottawa Light Rail project: Ottawa Transit Partners led by Vinci; Rideau Transit Group led by ACS Infrastructure Canada; and Rideau Transit Partners led by Bouygues.

German tunnel upgrade
Open invitation to tender for the structural and operational upgrade of the 1,527m-long Gernsbach tunnel on the B462 highway. Further information from Lars Lau at RPK, tel: +49 721926-0. Deadline 13 December.

Record third quarter for Atlas Copco

SWEDEN

Above: Ronnie Leten, Atlas Copco president and CEO

Atlas Copco's third-quarter results show record revenues and profit margins. Third quarter revenue increased by 21 per cent to SEK 20.74bn (USD 3.17bn). Operating profit was listed as SEK 4.8bn (USD 733.24M), a margin of 23.1 per cent.

"Our performance in the third quarter was very strong and we achieved good growth figures, especially in the United States and China," said Ronnie Leten, president and CEO of the Atlas Copco Group. "Considering the softening we have seen in the construction industry and the generally uncertain market situation, we have reviewed our contingency plans. We are confident that our operations are fit and well prepared, however the market develops."

The company reported that demand is forecast to weaken in the short term though the company is still looking to expand and add new technologies to its range. Leten added, "Since July we have been operating with four business areas and have already started adapting the structure of some customer centres, which will help us drive organic growth."

Caterpillar VP changeover

USA

Caterpillar vice president Chris Schena will retire in July 2012. Mark Sweeney, who was most recently operations director for the company's electric power division, will succeed him.

Caterpillar group president Rich Lavin said, "Since joining Caterpillar in Belgium in 1972, Chris Schena has demonstrated outstanding business leadership skills with a proven record of delivering superior operational results while always maintaining a focus on developing people within his organizations.

"During his distinguished career, Chris has provided leadership to Caterpillar business units and operations on three continents. He was a pioneer of lean manufacturing processes while leading Caterpillar's operations in Brazil in the late 1990s and as a result, Caterpillar's manufacturing operations in Brazil remain among the very best within the company [...] Mark Sweeney is an ideal fit for this role."

VMT opens US office

USA

VMT has launched a new office in Washington, US a spokesman last month told *T&TI*. Growth in the country spurred the expansion. A VMT spokesman cited a number of large-scale infrastructure projects on the East Coast and West Coast.

The spokesman added that this and other projects required local technical support from VMT personnel. The company will offer round the clock support from its new office, which the spokesman said was desired by the company's US client base.

Headquartered in Germany, VMT had three other country locations before the North American subsidiary brought it to five. These were China, Australia and Russia.

Hitachi Zosen moves west with colossal Alaskan Way contract

Hitachi Zosen's factory in Osaka, Japan, where the 17.45m-diameter EPBM will be manufactured

Japanese manufacturer Hitachi Zosen last month signed the contract to construct the 17.45m-diameter TBM for the 2.8km Alaskan Way Viaduct Replacement Tunnel in Seattle, Washington, USA. The signing marks a major step in the Japanese giant's push into western tunnelling markets.

"Signing this contract gets us one step closer to taking down the vulnerable Alaskan Way Viaduct," said Washington Governor Christine Gregoire. "This state-of-the-art technology allows us to keep SR 99 – and the region's economy – open for business during construction to replace this critical state highway."

The machine will cost the Washington State Department of Transportation (WSDOT) some USD 80M.

In July, Hitachi signed a letter of intent with the Dragados USA-Tutor Perini JV: Seattle Tunnel Partners, the WSDOT's design-build contractor for the tunnel project. The letter of intent allowed the Japanese firm to begin preliminary design of the machine in the summer.

By signing the new contract, Hitachi can complete design of the 17.45m diameter machine, which will be constructed in the firm's Sakai Works, a factory in the Sakai industrial zone of Osaka, Japan. Established as a shipbuilding plant in 1965, the factory was reborn in 2008 as a product-mix plant for industrial machinery, including tunnelling shields, as well as other large steel structures.

Hitachi told *T&TI* the machine will be manufactured in EPB configuration with cutters to deal with 'various geological conditions'. It has been designed specifically to minimise settlement and damage to buildings along the alignment. It will also be equipped with two erectors to speed the placement of segments.

Once completed, the EPBM will be barged to Seattle and assembled at the south end of downtown in early 2013. The machine will be launched from a pit near the Seattle sports stadium where the crews began demolishing the southern half of the viaduct last month.

"This will be a truly amazing machine," State Transportation Secretary Paula Hammond said. "At 17.45m in diameter and more than 91m long, it will be about the size of Washington State Ferries' largest vessels."

Seattle Tunnel Partners project manager Chris Dixon said, "At any given time there will be up to 40 workers inside operating the machine, monitoring ground conditions, maintaining equipment and working to ensure that tunnelling goes smoothly."

A Hitachi Zosen spokesman told *T&TI*, "The machine will be one of the world's largest TBMs, and certainly the largest we have built. […] Demand for TBMs is steadily rising, though mainly for subway construction projects in newly emerging economies such as China and India, as well as advanced economies such as Singapore.

"With over 1,300 TBMs now delivered by us to Japan and overseas, Hitachi Zosen aims to continue to accelerate expansion of the TBM sector of its business to serve this rapidly growing market.

The spokesman added, "Following our shield tunnelling collaboration agreement with [China-based] Beijing HuaSuiTong Boring Equipment in 2008, and the opening of the dedicated Sakai TBM factory later that year, ten orders received in 2010 and rising international demand generally has also necessitated the opening of 'Ariake Works' in Kumamoto."

As *T&TI* went to press crews were scheduled to begin utility relocation and other preliminary tunnel work in late October. Excavation of the tunnel launch pit will begin next year, followed by tunnel boring in mid-2013. The USD 1.35bn tunnel is scheduled to open to drivers in late 2015.

Jon Young and Alex Conacher

Edilmac's new Atlas Copco Robbins 73RVF C at its first job site on the Chiascio Dam water project in Umbria

Raisebore upgrade drives Edilmac on

Specialist contractor Edilmac dei Fratelli Maccabelli has been busy putting to work an upgraded Atlas Copco Robbins 73R with a new variable frequency drive and other package components. Maurice Jones reports from Edilmac's headquarters and the Sedrina limestone mine in Bergamo, Italy

The latest addition to Edilmac's fleet of nine raiseborers is a 'new' Atlas Copco Robbins rig. It is a major upgrade of the contractor's existing Robbins 73R rig with hydraulic drive. Only the main structural parts: mainframe, cross head, columns and hydraulic thrust cylinders of the 31-year-old rig remain.

The raiseborer is already on it second job in the half-million-tonne-per-year Sedrina limestone mine, not far from its base in Gorle, Bergamo, Italy, between the city and the foothills of the Italian Alps. Its first task was at Val Fabbrica, for the Chiascio dam hydro project, in the Perugia area. The need was for a ventilation shaft linked to a complex of irrigation aqueducts for agricultural use.

Adriano Facchinetti, technical manager for raiseboring at Edilmac says that despite the strata content on the first task, it was not difficult to bore and carried marly lenses in cemented, quartzitic sandstone. The result was a vertical shaft, 280m deep and 2.44m in diameter. A pilot hole was first drilled using a directional drilling tool (rotary vertical drilling system - RVDS) made by Micon, to ensure high accuracy in mixed and karstic ground with a long bore. The karst structure prevented the use of normal directional drilling with high-pressure water, so the new drill, of which this was the world premiere on site, employed air drive.

Following this initial drilling, the Robbins 73RVF C then came into play.

"Thanks to the newest technologies available, and to the technical choices made during the upgrade of the machine, this is now powerful almost as much as an Atlas Copco Robbins 83," reports Edilmac, "keeping the dimension and weights of a Robbins 73."

Sedrina mine

Edilmac has been working at Unicalce's Sedrina mine as development contractor ever since underground exploitation of the limestone resource started in 1978. This was related to a decrease in open quarry work, which was becoming impractical in

the limited space available in the valley, until production from the quarry fully ceased in 2000. Now the mine reaches from the lowest tunnel to the top quarry bench; a height of 430m.

"Our first shaft was excavated in the same year ('78) as we started in the quarry, and we drove the first tunnel in 1986," relates Facchinetti. "We've bored all sizes from a pilot bore diameter up to 5.76m, and all with one-pass reaming. The 5.76m bore is still working as a main mucking shaft."

At Sedrina Unicalce produces mainly fine lime and slaked lime (Calcium Hydroxide) for a wide range of industrial uses at an average rate of 2,000t per day. Poorer quality limestone that is excavated is crushed to aggregate sizes for road construction etc. The total rock excavated is around 4,000t per day.

Nearly all extracting now takes place from a series of large 'rooms' or open stopes, with tunnel and shaft connections that are the responsibility of Edilmac under a series of contracts.

Full product processing takes place on site in the former quarry in a valley where space is at a premium.

Edilmac completed its first pilot hole in 35 hours, followed by reaming back to 3.05m in one pass. The reaming progress rate was 0.65m/h in the 160MPa UCS massive limestone from a depth of 116m.

At Sedrina mine the main mining method is to create large rooms with intervening support pillars. Each of the main rooms is planned as 120m high, 40m wide and 180m long, with a 40m wide supporting pillar between. First the zone is prepared by development tunnels at three levels (top, middle and underneath) from which blastholes can be drilled later. At the end of each room a rock pass and slot is created by raiseboring.

When *T&TI* visited the mine the raiseborer was being set up at the end of room C8, with the power packs, cooling unit, operator's cabin, and an Atlas Copco XAHAS 536 mobile compressor for pilot hole cuttings removal, all in close proximity. The Edilmac crew was changing the drive head for one with a bigger thread to suit larger 11.25in (286mm) diameter rods rather than the 10in (267mm) diameter rods used before.

The raiseborer to used to form the first opening at one end, approximately 116m deep, using a pilot hole 12.25in (311 mm) reamed out to a full 3.06m diameter. The rooms are also in rows on two levels, with main rock removal level drives beneath each, thus exploiting the resource to the maximum extent without caving or additional support in most cases.

"The limestone rock here at Sedrina is much harder (around 160 MPa UCS) and massive,' says Facchinetti, "so it will be a real test for the new rig (compared to Chiacio). But it now has a high power at 450 kVA instead of 350 kVA. We are a lot happy with the 'new' rig. Really a lot happy. It really is an improvement in performance on the old 73R. The rod handling system is also a little better, but the real improvement is in performance."

After this bore at Sedrina mine the 73RVF C is destined to carry out further rock pass provision in slots at the end of the parallel rooms. This allows the blasted limestone to be transported most efficiently by gravity to crushers and conveyors at a lower level.

The rock removal tunnels with belt conveyors all reach the surface at the old quarry face to drop the crushed material onto the main old quarry level. From there the rock feeds through one of three, 10m diameter shafts, that were also excavated by Edilmac, to reach the main preparation plant.

Above: Entrance to Unicalce's compact preparation plant in Sedrina with mine behind Right: Left to right, the new hydraulic power pack, cooling unit, electrical powerpack and switchgear, and the raiseborer itself with control cabin behind

The three levels of room development tunnels are also the responsibility of Edilmac using their two Atlas Copco L2C jumbo drilling rigs. These tunnels are then used by Unicalce production teams to carry out drilling with fans of blast holes. Formerly only one tunnel per level per room was driven, through the centre of the block, but now two tunnels are driven at each level on the edge of the demarcation. This gives better blasting results.

Retrofitting

The upgrade of the raiseborer was made possible by cooperation between Atlas Copco, Edilmac and the electrical motor manufacturer in Austria.

"Raiseborer rigs can easily last for 20-30 years," explains Atlas Copco Line Product Manager for raiseborers, Johnny Lyly, "but even with good maintenance their performance will be much less than what is currently possible. The mechanical side, mainly gearboxes, can be easily updated, but the installation of modern hydraulics and electric control is more difficult, which is why we have introduced upgrade kits. These can include new power-packs and drive systems for electric or hydraulic motor upgrades as the customer prefers."

With hydraulic systems the twin powerpack supplies both rotation and thrust, but with electric drives there is one powerpack with electrical controls for the electric drive motor and a hydraulic power pack for the thrust unit. The electrical controls include the variable frequency drive for excellent speed and torque control, and a resistor unit for controlled stop in the event of power loss.

"After trials, Edilmac has a preference for AC electric motors, due to their higher efficiency compared to hydraulic motors or DC electrics, which means variable frequency (VF) drive control," explains Lyly. "An AC motor with VF control can be adjusted for speed and torque similarly to a DC motor, but with the higher efficiency. It was decided to go for a complete upgrade with modern equipment, not only for the drive but for control and cooling systems."

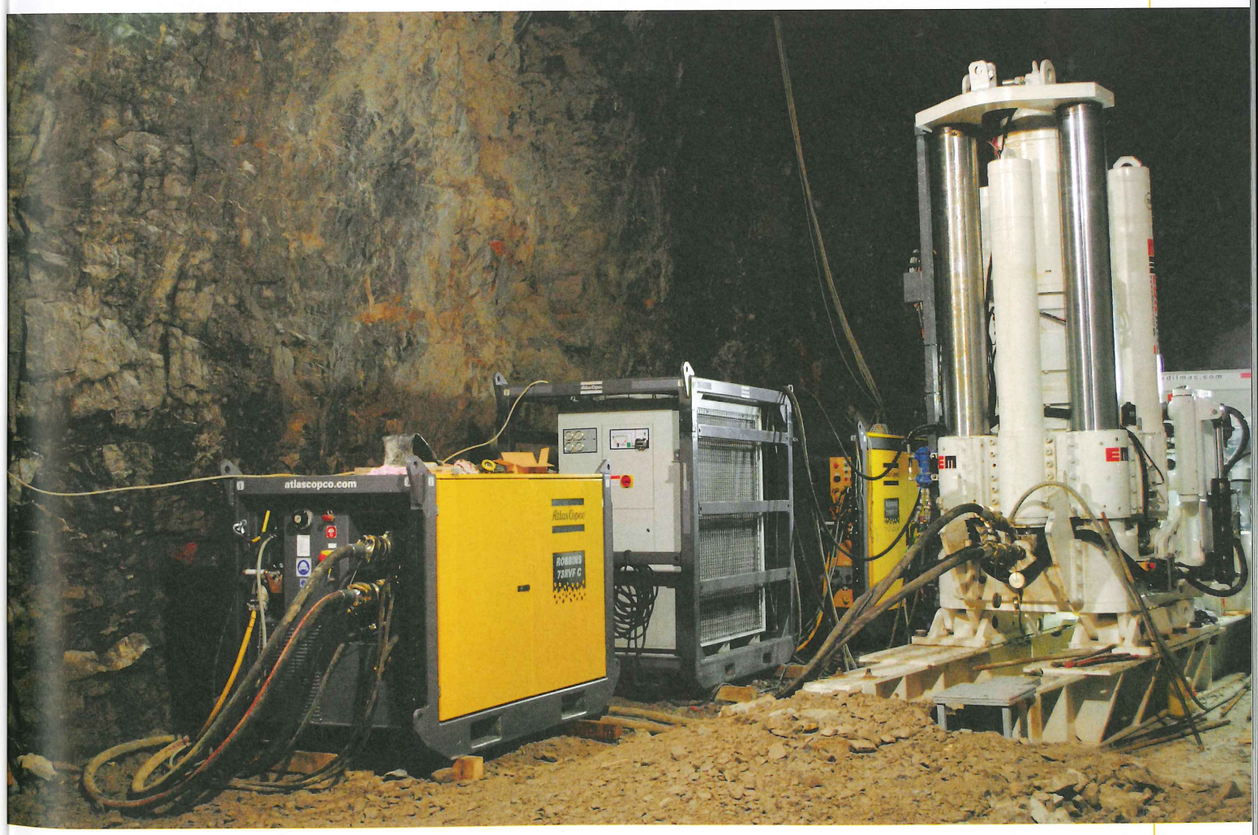
The retrofit package for Edilmac's existing Atlas Copco Robbins 73RH consists principally of the water-cooled AC electric rotary drive motor, a new gearbox, a hydraulic power pack for thrust, Atlas Copco's universal computerised rig control system (RCS) with compact electronic console, and a self-contained cooling unit for the hydraulic system and drive train that requires no external water supply.

Development

The new package has been backed by a lot of internal development at Atlas Copco. "We hadn't built a raiseborer with a variable-frequency electric drive at Atlas Copco since 2002, and there has been a lot of component development in the meantime," explains Lyly. "So we had to test the whole drive-train first. Using a new, water-cooled compact motor, we carried out the tests over two days with the powerpack at the premises of the motor manufacturer Elin in Austria, with our system connected to a load motor for simulations. These included stalling, backspin and fluctuating load to simulate all the conditions that might occur with a raiseborer. And the results were very good, meaning we could go ahead with the retrofit work.

"In the meantime Edilmac had fitted the new gearbox themselves, and so we put the two together at their Gorle premises, carrying out further successful tests for another two days," reports Lyly. "One result was a big increase in torque to 250 kNm. The rig could then be designated as an Atlas Copco Robbins 73RVF C."

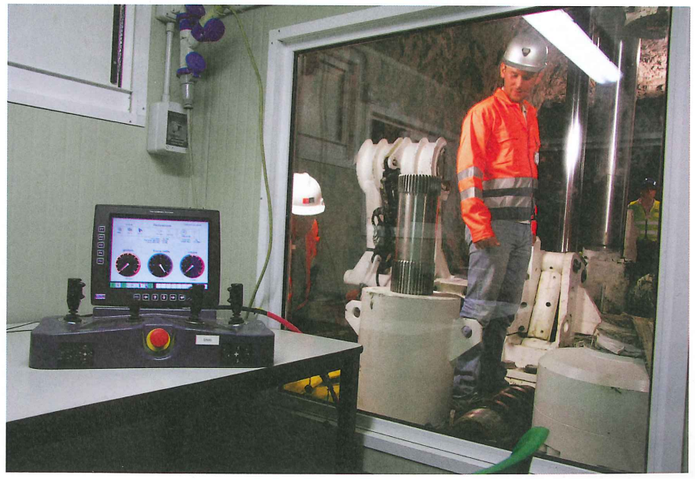
A small but important part of the retrofit, for operator acceptance, is the desktop control console, with a flat-screen display portraying a simple operator layout normally showing rotary speed, net thrust



force and torque as analogue dials. The system also gives a lot of information feedback on performance and faults, which can help in maintenance.

Atlas Copco engineers are also developing a reporting system that can be integrated with the existing Tunnel Manager software. As only instrumentation cables should go into the cabin, there is at lot less mechanical noise for the operator to tolerate during excavation.

More Atlas Copco Robbins 73R raiseborers have been sold worldwide than any other raisebore system says Atlas Copco, and now, with the upgrade to the 73RVF C, it has also become the most energy-efficient raiseboring system in the Atlas Copco range.



Improvement acceptance

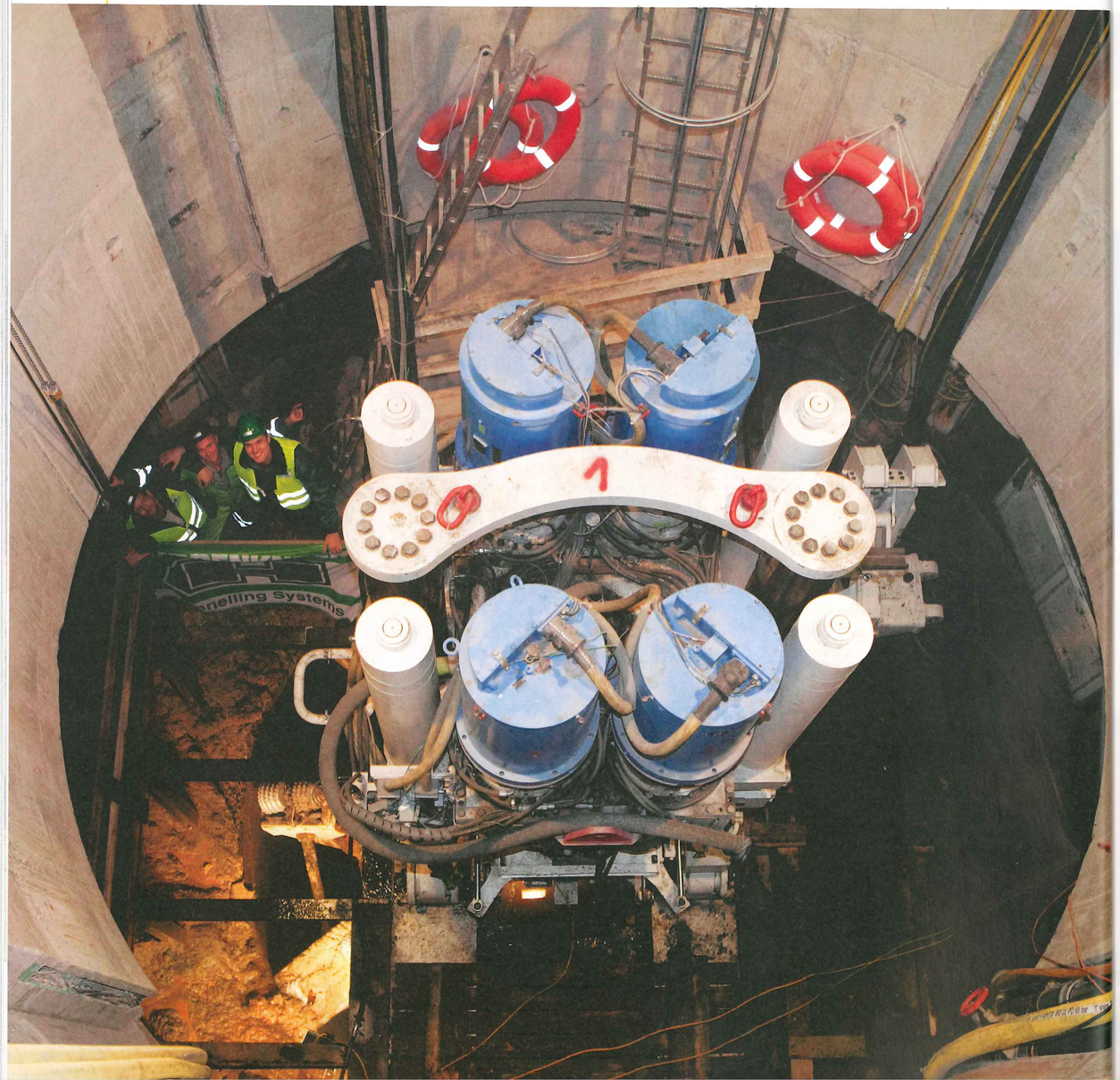
Explaining some of the finer points of raiseboring Facchinetti says, "Raiseboring is not really a matter of speed, but getting through without problems, so the rig's available torque and thrust are very important to keep on boring without jamming. This rig's new 280kW VF motor gives a maximum torque of 250kNm instead of the previous 180kNm."

On the compact control system with easily understood instrumentation on a flat screen desktop console, Facchinetti says, "The new console really is an improvement too. The operators like it a lot.

If all goes well we are looking to upgrade our other 73R raiseborer next year, also with a VF AC electric drive."

Above: Some of the Edilmac team in Sedrina including (left) Roberto Ferrari, vice-foreman and shotfirer, (right) Dr Ing Adriano Facchinetti, RB technical manager (2nd right) Ing Manual Carli, and (3rd right) Sergio Moioli, RB foreman [Photo: Rossana Sinestesia
Left: The compact operator's panel with simple instrumentation, as rig preparation and drill-pipe drive changing is being carried out (Photo: Rossana Sinestesia)

Raising the pressure



Left: **Breakthrough of the Herrenknecht raiseboring rig 550 VF**
Right: **Figure 2, a schematic showing the shafts and tunnels for the new turbine**

Adding an extra turbine to the Vianden pump storage plant in Luxembourg requires a new vertical pressure shaft. Benjamin Kunstle and Alexander Frey of Herrenknecht explain how the raiseboring is sinking in

The pump storage plant on the Vianden reservoir, Luxembourg, was put into operation in 1963 with nine sets of turbines. In the mid-1970s it was extended to include a 10th unit.

Pump storage plants are primarily used for peak load protection. When the national grid has a surplus of energy the turbines pump water from the lower reservoir via the shafts to the upper reservoir. The surplus energy is thereby transferred into potential energy in the upper reservoir. At peak demand the water is released back through the turbines and the electricity (minus a little loss) is put back in the grid.

The Vianden plant has a capacity of 1,100MW with its 10 turbines. The operator, Societe Electrique de l'Our (SEO) is extending the capacity by 200MW through the installation of an 11th turbine, which uses the existing upper and lower basins, but has its own system of waterways and inlet and outlet structures.

The construction of the facilities to accommodate the 11th machine is under the responsibility of the consortium PSW Vianden Los One, consisting of the companies Zublin, Strabag and Jager. The contract includes, among others, the construction of an inlet and outlet tower in the upper reservoir, followed by a vertical pressure shaft (see figure 2, below).

Construction of the pressure shaft

The JV awarded the contract for the construction of the pressure shaft to Edilmac dei Fratelli Maccabelli. The pressure shaft extends over 300m from the upper reservoir down to the powerhouse level. After passing through a vertical bend, a 240m long, shallow inclined pressure tunnel connects to the power house. The vertical shaft, manifold and pressure tunnels are equipped with a steel armour, which is designed to accommodate the full, potential outside water pressure. The pressure shaft and tunnel will have an internal diameter of 4.5m.

The project area is located in the clayey to silty fine sand of the Siegen and Ems steeps of the Lower Devonian, whereby generally very low to impermeable ground water conditions were assumed. According to the tender documents, the raiseboring method was selected for the construction of the vertical pressure shaft.

After the contract was awarded in April 2010, Herrenknecht developed the 550 VF raiseboring rig. Here, customer requirements were incorporated. The successful factory acceptance test took place on October 5, 2010. Favoured by the compact, modular design, the rig could be delivered from the factory in Schwanau to the Vianden site with only a few transporters and it arrived on site on 8 October 2010.

The procedure

When using a raiseboring rig for a shaft construction in stable rock, the handling of the rig, over the shaft starting point, takes place in a first step by means of a crawler track or crane. From here the vertical pilot hole starts with the drill bit facing downwards (see figure 3, page 24). If necessary, the pilot hole can be carried out at an angle of up to 45°. The debris is flushed out during the pilot hole excavation by a flushing medium (usually water or air). Depending on the drilling depth, additional drill rods are successively installed until the target depth is reached in the existing lower tunnel or cavern. The pilot hole drill bit is then removed and the reaming head

Above: **Figure 1, The Vianden pump storage plant is near the German border**

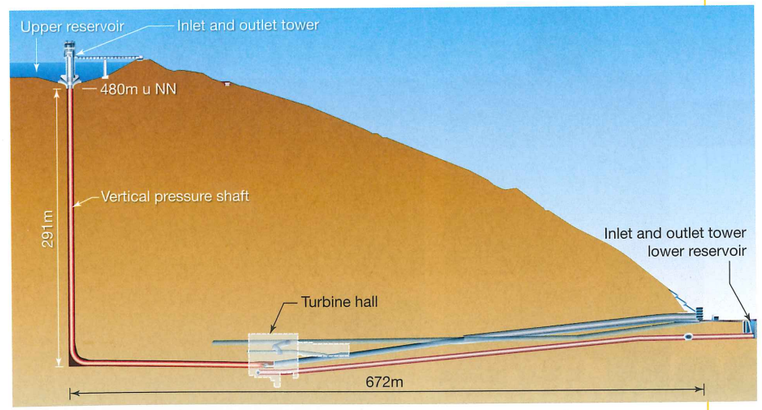
(typically 1-7m in diameter) mounted on the drill string.

The rig pulls up the reaming head with the drill string. Through the rotation of the reaming head, the rock is crushed and falls down where it is removed.

The shaft is reamed from the bottom to the top by the diameter of the reaming head to the target dimension.

Compared with the conventional shaft sinking methods, the use of a raiseboring method significantly increases the safety of the personnel, since they work outside the actual shaft. In addition, significantly higher construction rates can be achieved. The shaft wall is generally smoother and over-excavation is reduced. Removing the muck from within the tunnel is often more efficient than excavating through the shaft being sunk. Since fewer staff are needed to operate the rig than with conventional shaft sinking, significant cost savings can be achieved here.

The RBR 550 VF by Herrenknecht is one



of the largest rigs of its kind ever used. It is distinguished by a compact, modular design and has a powerful and highly efficient centre-free drive. Herrenknecht's variable frequency controlled drive concept allows for variable speed and torque control. The rig is designed for shaft lengths of up to 1,000m. The mechanised drill pipe handling ensures more efficient operations as well as greater safety of personnel during installation and removal of drilling rods.

Drilling Vianden

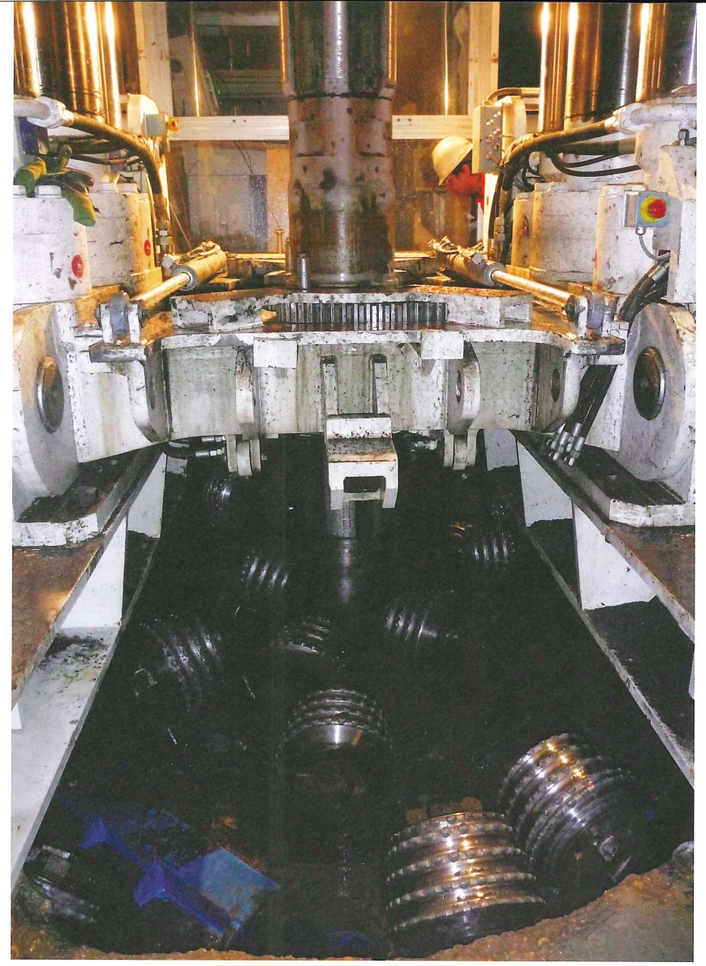
During on-site assembly, the construction team had to mount the RBR 550 VF rig in a 45m high inlet/outlet tower in significantly confined space. Nevertheless, the on-site assembly was completed in three days.

On 16 November, 2010, the rig was put into operation as planned and the 15in (381mm) diameter pilot hole was drilled. Once the pilot hole was sunk the 5,460mm diameter reamer was fitted and the shaft excavated at 10m per day on average with a maximum of 18m achieved in one day.

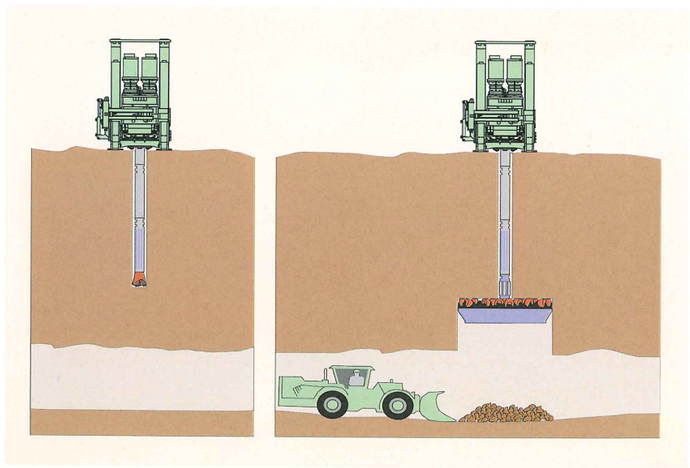
With the constantly changing geological conditions of loose to hard rock with maximum compressive strengths of up to 130MPa, the machine control system proved to be particularly favourable, ensuring a failure-free boring process. The time schedule for assembly, pilot boring, reaming and disassembly was met after 40 drilling days. On January 18, 2011 the drilling of the 282m long shaft was completed (see photo, above right).

Outlook

The RBR 550 VF successfully completed its premiere drive at Vianden with high reliability. The pressure shaft for the 11th turbine of the Vianden pump storage plant was quickly and safely excavated. The commissioning of the turbine is scheduled for the third quarter of 2013. After its use in Luxembourg the next task for the rig is at hand: a 4,760mm diameter and 280m deep ventilation shaft for a bypass tunnel in Bolzano, Italy. At the construction site in Bolzano the crawler unit of the RBR 550 VF proved its worth, as the location was difficult to reach over tough terrain.



Above: **The 5,460mm reamer head of the RBR 550 VF breaks through;** Below, left: **Figure 3, raiseboring is undertaken by first drilling a pilot hole then reaming upward**



Key data

- Project: Pump storage plant Vianden, Luxembourg
- Client: Societe Electrique de l'Our S.A.
- Customer / machine operator: Edilmac Dei Fratelli Maccabelli
- Equipment: Raiseboring Rig 550 VF Vianden
- Shaft depth: 282m
- Shaft diameter: 5,460mm
- Pilot hole: 15in / 381mm
- Drilling start: 16 November 2010
- Breakthrough: 18 January 2011
- Best reaming rate: 18.2m on 12 January 2011
- Rock strength: Up to 130MPa

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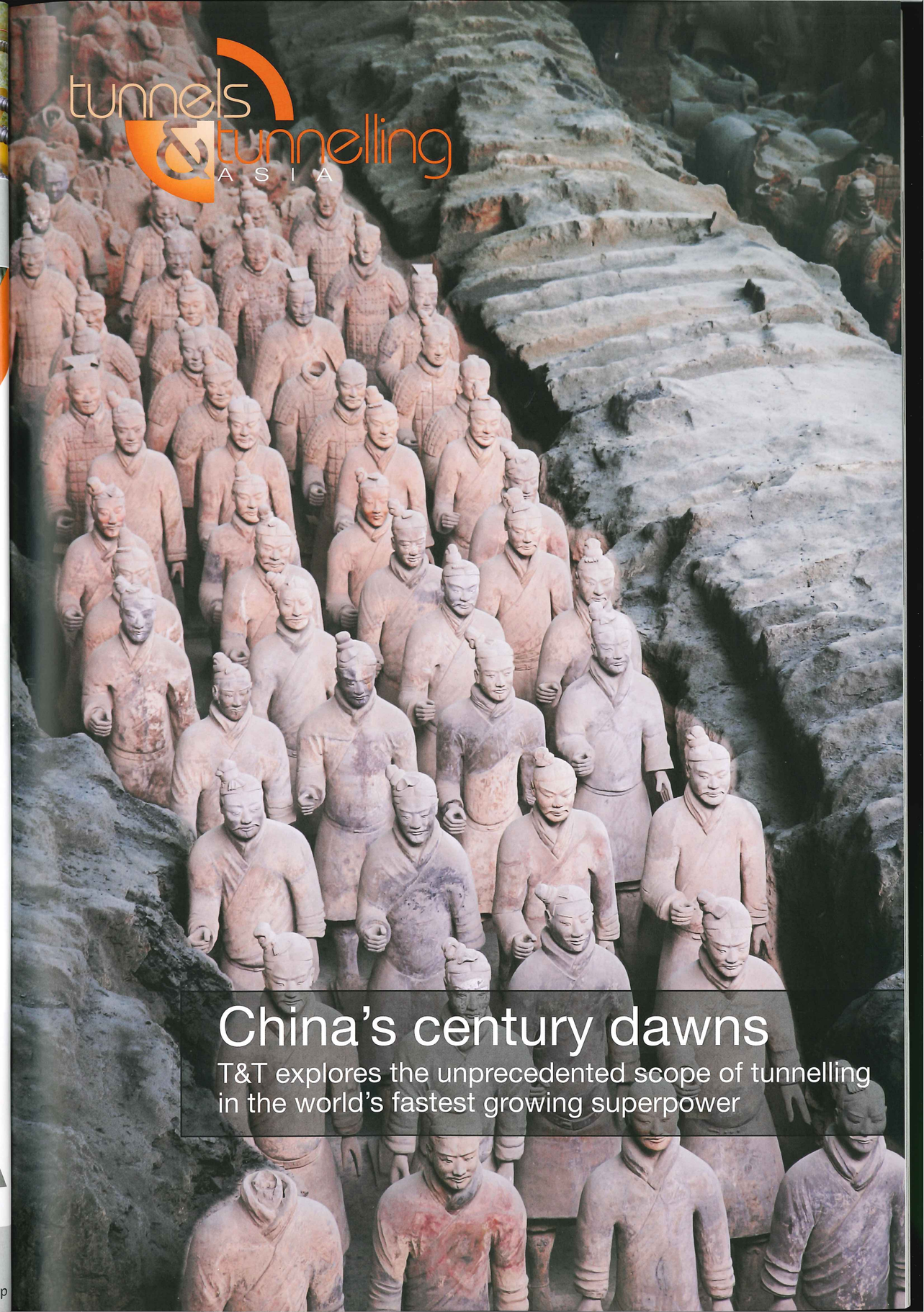
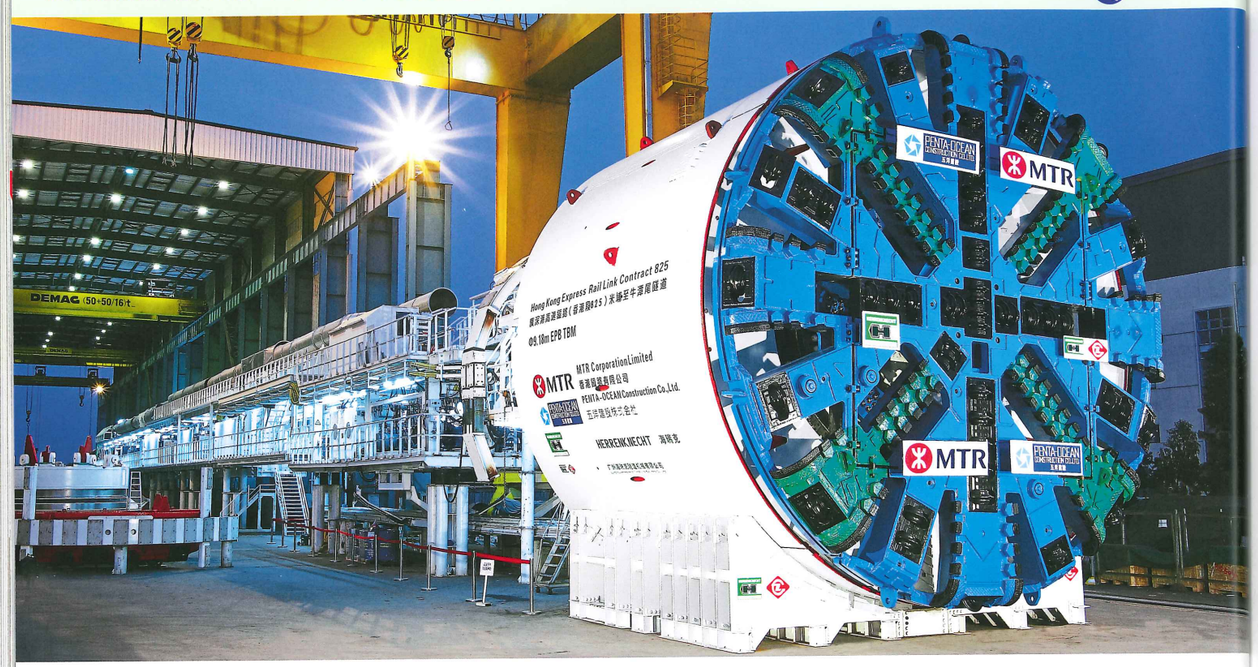


China's century dawns

T&T explores the unprecedented scope of tunnelling in the world's fastest growing superpower



LAUNCHING OF FIRST DRILLING GIANT FOR XRL HONG KONG SECTION.

When the "Guangzhou-Shenzhen-Hong Kong Express Rail Link" (XRL) has been put into operation, this will reduce travel time by 40 million hours annually. The present travel time of 100 minutes will then be reduced to about 50 minutes. This involves building 140 kilometers of new high speed route between the metropolis of the Pearl River delta from Kowloon to Shenzen and Guangzhou.

Herrenknecht is manufacturing a total of six large tunnel boring machines (Ø 9.18m – 13.17m) for the Express Rail Link: one Mixshield for the Shenzhen section, four Mixshields and one EPB Shield for the Hong Kong section to excavate a total of 25.8 kilometers of tunnel. The first drilling giant for the Hong Kong section was put into operation at a ceremony on August 10, 2011. The Herrenknecht EPB Shield S-620 was given the name "Zhao-jun". This is the name of a beauty known from ancient China and it stands for "communication and connection". It was chosen from among 33,500 proposals in a public competition which was organized by the client MTR Corporation. The Herrenknecht Mixshield S-550 (Ø 13.17m) is already working underground for the XRL in Shenzen.

SHENZHEN AND HONG KONG | CHINA

PROJECT DATA	CONTRACTOR
S-620, S- 550, S-623, S-624, S-630, S-631 **1x EPB, 5x Mixshields** Diameter: 1x 9,180mm, 2x 9,250mm, 2x 9,900mm, 1x 13,170mm Installed power: 1x 2,800kW, 1x 4,200kW, 4x 3,150kW Tunnel lengths: a total of 25.8km	S-550, S-623, S-624: China Railway 15th Bureau S-620: Penta Ocean Construction Co. Ltd. S-630, S-631: Dragages Hong Kong Ltd., Bouygues Construction

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In the belly of the beast

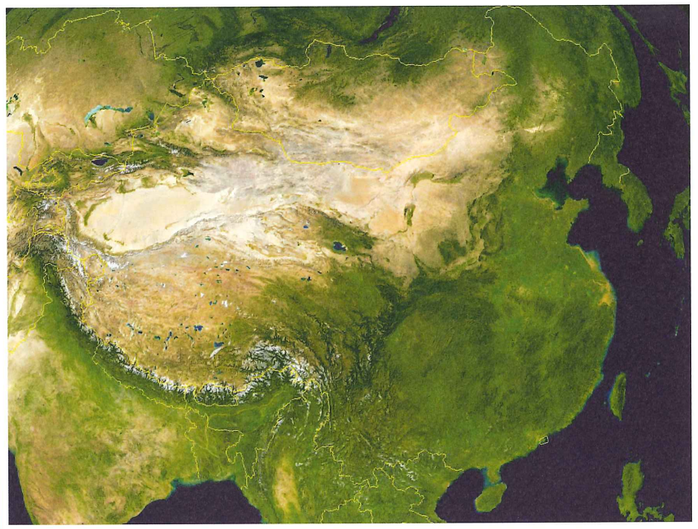
T&TI cuts through the bureaucratic smoke and mind-boggling statistics to unearth what it means to set up shop in the world's fastest growing superpower. Alex Conacher enters the dragon's lair to speak with Paul Jenkins of Mott MacDonald and Gary Ge of Arup

Unimaginable scale in every way is everyone's first thought of China. And the shrill hysteria of financial reporters when growth in the People's Republic drops below double digits is testament to this. Besides the usual figures of 1.3bn people and foreign exchange reserves in the trillions, tunnelling is of a scale that the West has never seen, and probably will never see. There is not space in this special report to devote a paragraph to all the major projects underway. In urban transportation alone some 50 cities in China are developing metro projects.

"The metros of China form the backbone of public transport," says Mott MacDonald's managing director of China Paul Jenkins. "There is a limited supply of cars permitted, which puts pressure on the metros – and quite rightly. In Beijing, for example, there is a lottery on who gets a car. The significance of this for tunnelling is that lines that opened two years ago in Beijing are already at capacity."

Jenkins has spent 26 years working in the Asia Pacific region. He says, "The tunnelling industry has expanded hugely over the last few decades, and in China it has been even more explosive. This is both in the number and diversity of projects, because you have to remember that in China you are starting from a very low base of infrastructure in many places, and so there is a correspondingly greater improvement to be made in towns and cities."

Right: Zhengzhou Metro Line One (see article on page 43)



Above: A satellite image clearly showing the water divide between the north west and south east regions of China, which is driving the need for water transfer tunnels

Recent years have seen a more intense effort by western companies to work in China, further driven by the economic turmoil in Europe and the US, but there has long been foreign involvement in the area.

Jenkins says, "Mott MacDonald has been around on mainland China for 35 years now and in Hong Kong for 50 years. It started in the early days on environmental projects, including the Shanghai clean up schemes. It's fair to say that Shanghai and other cities were in a pretty bad way at this time, but major improvements have clearly been made over the past few decades.

"We are actually just about finishing the Shanghai environment and wastewater projects now, after 30 years of working on the various jobs to deal with sewage and flooding," adds Jenkins.

"Besides the metros come our major projects at the moment, the high speed Passenger Dedicated Lines (PDLs). This for us relates to around 300km of tunnels, for which we perform the role of the Jiangli. This is basically a construction supervisor role, a legal requirement for all construction projects in China, but on PDLs the Jiangli must be linked to a foreign consultant. In effect, the most senior person controlling the work of a local Jiangli must be an expat."

Jenkins says, "A single Jiangli will look after a 30-60km section. Around 70 per cent of the sections we've got are through tunnels, which looks to be a reliable indicator for the whole. So, of 10,000km of PDL, you are looking at 7,000km of tunnelled works. And these lines are absolutely all over, we have some portals that are 3,000m above sea level and take all day just to get to – it's unbelievable."

Jenkins says that the routes between the main cities are all in now, the next batch to come are the strategic ones such as airports, which are unable to deal with the incredible amount of business travel that flows through them. To counter this they will be linked to the rail networks.

Growing pains

Red zone

Gary Ge, associate and leader of Arup's China infrastructure team, says, "Large state-owned companies still dominate the market in China, and it is unlikely for international firms to win the entire or major design packages. These are also our most regular JV partners [rather than European colleagues]."

Jenkins explains, "We cannot perform detailed design work as things stand in China. To win this sort of work, you need a Grade A Design Licence. These are not awarded to foreign entities and the majority are held by a vast number of enormous Chinese 'Design Institutes' (DIs). We can still perform management, quantity surveying, feasibility work and construction supervision of course.

"We also had a problem five or six years ago on the Chengdo to Xi'an line. It was suddenly decided that all foreign input was to be stopped and we were booted off the project. Two or three lean years for us followed – so you see, it is not always 'up and up' in China – and then about 18 months ago we started picking up these PDL jobs and revenues are expanding."

Starting from scratch

China has come a long way in a few short decades from a 'very low base of infrastructure'. This has brought challenges, and also opportunity for tunnellers plying their trade in the country.

"Much of what you might call the 'easier tunnelling' has now been taken as far as it can," says Jenkins. "The cut and cover parts of the Beijing metro and so on. Now China has to get into more difficult kinds of tunnelling, passing close to and underneath existing tunnels and interchange structures. There are some problems emerging too, similar to London in some ways in the use of underground space. It is something that Hong Kong has taken to a fine art, planning underground space use and lessons need to be learned by the mainland.

"It wasn't carelessness or a lack of skill, it was just a lack of knowledge of how metro systems develop over time. This brings us back to the design licences. The Chinese DIs operate mainly according to guidelines. This is not just in the form of separate Chinese Standards.

"If you take railway tunnelling, for example, all works are undertaken according to the Ministry of Railway's design guidelines. The DI will assess a project's requirements, the geology and so on and then come up with a solution based on guideline manuals, for example coming to the conclusion that: 'this project requires a tunnel of type 3B'. There is less finite analysis, less geotechnical investigation, and these guidelines are set in stone. This has worked until now."

Jenkins adds, "With more challenging tunnelling emerging, more analysis is required, this cannot be avoided. A more open market is needed, and China will have to change over the next 10 years to bring it more in line with the rest of the world, with DIs operating more like traditional consultants. Mott MacDonald and others are waiting for that day and we are in discussion with the DIs over collaboration. This is essential, as licence laws cannot change over night.

"There are also not many private DIs to buy and there is always the risk that if you do acquire one, they lose their licence and then you are stuck with a lot of designers unable to design."

Chasing the dragon

Benefits of strong leadership

A more positive side of working in China is the surety that if the government begins a project, nothing can halt it. Jenkins tells *T&TI* that it is exciting to be an engineer in Beijing. Projects shoot through the early phases and, even at construction, progress is faster than is often dreamed of in the West. And this is not just some government-led push into tunnelling. Chinese leadership is responding to an overarching need for these projects in the face of an ever growing, and ever demanding population.

The north-south water supply projects are an example of this. There is very little water in the north and west of China compared to the south and east (see satellite image, opposite). The government has been investing in an astonishing array of canals, tunnels and aqueducts, stretching for thousands of kilometres.

Expanding away from China

An emerging trend to seek work abroad is emerging in Chinese companies. This is not unheard of even in multinationals based in China, stretching back out into the global market in JV with China-based enterprises. Jenkins of Mott and Ge of Arup have both experienced this.

"We are always trying to get into new markets," says Jenkins. "Going overseas with Chinese contractors is something we are looking at. We act as designers on Chinese-funded interests. Despite the domestic focus of the latest Five Year Plan, this is a large market that we've identified."

Ge gives the other side of the trend: "By 2010 around 87 per cent of the 85,000km State 7-9-18 Network had been completed and was in operation. In the Chinese 12th Five-Year Plan, high speed rail and urban rail are the priorities of development."

However, the construction plans of high speed rail are under review by the government after the Wenzhou high-speed train crash on 23 July 2011.

Ge adds, "Because of this situation, some state-owned enterprises are making adjustments to their development strategies, i.e., intending to explore more overseas opportunities. This is of strong interest right now. For example: in conjunction with the China Communications Construction Company, Arup is carrying out the feasibility study and preliminary design for the multi-lane road tunnel under the Karnaphuli River in Chittagong, Bangladesh. The tunnel is the first river-crossing tunnel in Bangladesh."

Above: The first of two Robbins EPBMs was launched on Lot 12 of the Xi'an metro in June 2010, and is now currently on its last section of tunnel. (See article on page 32)

On the horizon

As *T&TI* goes to press the estimate is that 5,940km of high-speed rail tunnelling is underway in China. This looks set to continue. Other tunnelling works just around the corner include a series of road tunnel connections between the six ring roads of Beijing to deal with the increasing congestion there.

Feasibility studies are underway, with construction possibly starting in 2012. Chongqing and Shanghai are also looking into this sort of project.

Flood relief for the south will also become a prominent interest of the government. Aecom is working on a Shanghai water transfer tunnel and Mott MacDonald is lobbying for combined tunnel solutions similar to the stormwater management and road tunnel (SMART) in Kuala Lumpur, Malaysia.

On the Hong Kong-Zhuhai-Macau Bridge-Tunnel, dredging has begun as well as the manufacture of casting basins for the immersed tube units.

Final word

T&TI presents a report on metro tunnelling under the fragile buildings of Xi'an's ancient city; the trying ground conditions on the Pinglu tunnel of the Yellow River Diversion Project (water supply); and Zhengzhou provides a case study for the metro construction underway in a huge number of Chinese cities trying to cope with the population boom.

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Tunnelling below China's ancient past

Below the city made world famous by the 1974 discovery of the Terracotta Army, tunnellers tread carefully to avoid disturbing other historical wonders of the 3,100-year-old resting place of the first Emperor of China, Qin Shi Huang. Desiree Willis, Robbins technical writer, presents this report

Xi'an, China, is a hodge-podge of the ultra-modern and the historical. Vast contemporary shopping malls compete for attention with ancient bell towers and 7th century pagodas. Once the capital of China, the 3,100-year-old city also served as the eastern terminus of the Silk Road. Despite the balance of old and new throughout the downtown area, Xi'an's transportation infrastructure has, until recently, been decidedly outdated. More than eight million people rely on surface transportation such as buses and taxis for travel within the city. That will all change in September 2011, when trial operations are scheduled to begin on Xi'an's first new metro route, the 26.6km Line Two. The city's 26.4km metro Line One is currently under construction, and will run from north to south through the downtown area. Ten TBMs, including two 6.2m diameter Robbins EPBMs, are currently excavating the new rail route, which travels directly below some of Xi'an's most sensitive heritage sites.

Unique geologic conditions

The new metro Line One will travel below the famed Bell Tower of Xi'an, built in 1384 during the Ming Dynasty. Ancient Xi'an was a walled city, and that wall still remains, dividing the area between 'Old Xi'an' and 'New Xi'an'. This wall, built in 1370, sits directly above the rail route's bore path. Geology includes everything from sand and clay to abrasive pebbles up to 80mm in diameter—conditions that can be harsh on TBMs. "Line One is very difficult; the most difficult section in the city," says Steven Zhou, Robbins project engineer. "The most critical issue is the mixture of pebbles with sand and soil. This can result in very serious wear to the cutterhead and cutters." Extensive studies of the Lot 12 site where the Robbins EPBMs are boring indicated layers of highly to moderately compressed loess in bands up to 10.1m thick. Below the loess layers and the water table is a 30m-thick layer of silty clay with moderately abrasive sand. Abrasive pebbles are found throughout the mix.

Tunnelling is made even more complex by a city-wide ordinance limiting settlement to ± 15mm; significantly less than the 25mm limit that is typical of most

Chinese tunnelling projects. The strict settlement guidelines, implemented due to the ancient structures, required specialised designs for the EPBMs.

The two machines are excavating Lot 12 of Line One for the 11th Bureau of China Railway Construction Corporation (CRCC). The parallel 3.6km tunnels pass through four cut and cover station sites—Changlepo, Wanshou Road, Kangfu Road, and Jinhua Road—under shallow cover ranging from eight to 22m. "The biggest concern for us was the control of settlement," says Zhai Xianxi, mechanical and electrical engineer for CRCC Bureau 11. "We wanted to ensure that the machines could keep the right earth pressure and control the output of the muck, and reduce the malfunction time. This would allow the machine to pass through any difficult layers as soon as possible."

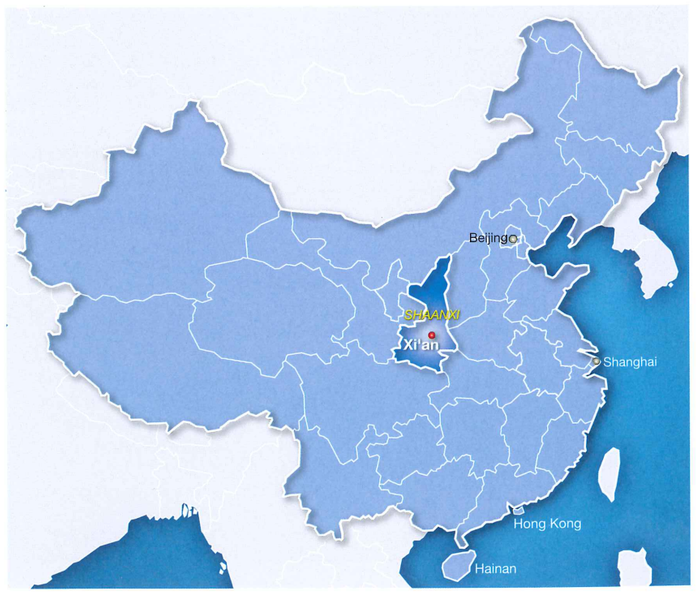
Maintaining face pressure through machine design

The Xi'an EPBMs were engineered to smoothly maintain face pressure in variable ground conditions and to maintain tunnel stability, from cutterhead design to active articulation.

Cutterhead design

Each machine was supplied with a spoke-type cutterhead, which utilises a large opening ratio to ensure a smooth flow of muck into the mixing chamber. The overall design of the spoke-type cutterhead allows for less abrasive wear due to the smaller surface area exposed to the face, compared with breasting plate cutterheads.

Once spoils have been scraped from the face, muck and additives are further mixed within the cutterhead, inside the mixing chamber. Two mixing bars are fixed in the machine—one on the inside of the cutterhead and one on the pressure bulkhead—to homogenise the muck as much as possible before it exits via the shaft-type screw conveyor. The uniform muck is better able to maintain pressure and hold the excavation face, while the shaft-type screw design ensures water tightness.



Foam/grout injection

Independent foam injection nozzles were also used on the cutterheads, to inject foam as well as bentonite and water for ground conditioning, depending on the geology present. The independent foam ports are used to consolidate the flow of muck and prevent clogging on one side of the cutterhead, which can lead to uneven wear.

To date foam has been predominantly used over bentonite and water because of its abilities to reduce the required cutterhead torque as well as overall machine wear. Insufficient foam injection has been associated with increased thrust and required power, as well as higher cutter consumption. A programmable logic controller (PLC) continuously regulates the variables of the additive system to prevent surface subsidence.

Active articulation

Multiple curves along the tunnel alignment range from 3,000m radii to a low of 1,000m, requiring active articulation to better stabilise segments. The setup engages articulation cylinders between the front and rear shields to steer the machine independently of the thrust cylinders. Flat joints in the articulation cylinders allow for two to three degree curve adjustments over the length of each segment or stroke.

The process allows the thrust cylinders to react evenly against all sides of the segment ring during a TBM stroke in a curve. Segment deformation, or racking, is a common cause of project delays that occurs when the passive articulation system is used in curves. Passive articulation does not utilise articulation cylinders independent of the machine's thrust cylinders, allowing the TBM to react against sides of the segments unevenly in a curved alignment.

Machine launch under challenging conditions

In June and July 2010, commencement of Xi'an's Metro Line One began with the launch of the two Robbins machines from Changlepo towards Wanshou Road Station—the first TBMs tunneling on the project. Eight refurbished Komatsu EPBMs were launched at later dates on the remaining lots.

The Lot 12 section was located in a densely urban area, with the tunnels travelling below a college, a hospital, and a marketplace. "The machines were launched in sandy soils with cobbles more than 200mm in diameter—a type of ground with high risk of settlement," says Jason Xiao, Robbins project manager. Crews continuously monitored the excavation rate and overall muck removal volume, by adjusting the thrust force, advance rate, and screw conveyor speed, while keeping the cutterhead speed low, at one rotation per minute. Bentonite was also used to improve soil conditions at the tunnel face.

Sections of collapsible, water bearing soils were also present in early sections of the tunnel alignment. Crews approached these sections with similar measures, including strict earth pressure control in the mixing chamber, paired with injection of bentonite and water for soil conditioning.

Minimising settlement

As of August 2011, one machine had recently completed its second section of tunnelling between Wanshou Road and Jinhua Road, and the other was on its last section between Jinhua Road and Kangfu Road in layered loess conditions. "The machine is currently boring about 10m below a viaduct structure," says Xiao. "So the demand on settlement control is even less than 15mm here. We are working to keep the appropriate earth pressure and control the output of the muck, while performing regular maintenance to reduce downtime through this section."

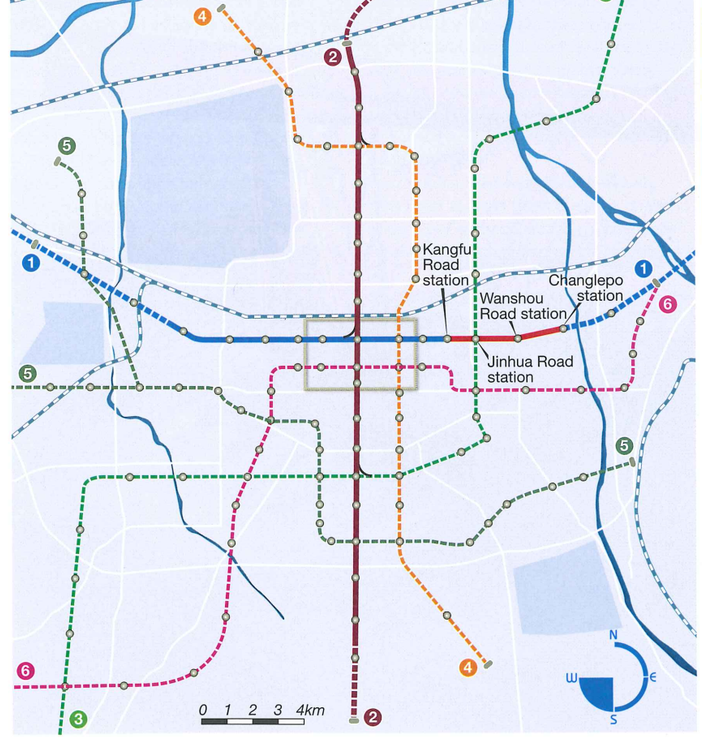
The last intermediate breakthrough, at Jinhua Road station, occurred on 28 July. Advance rates for the Left Line EPBM have been good—up to 579m (386 rings) per month and 36m (24 rings) per day. Planned maintenance was performed while in the cut and cover area, such as changing of cutters and tail seal brushes as well as checkups of the hydraulic system and electrical system. Semi-segment rings consisting of the invert and two segments were installed to allow the machine to 'walk' through the 140 m long station site.

Advance rates for the Right Line machine have been similarly high—up to 453m (302 rings) per month and 39m (26 rings) per day. Settlement has been kept below 15 mm with an average settlement of 5mm. "We have been able to control settlement, and we feel we are mastering the EPBM more and more," said Xianxi.

Tunnelling should be complete in November 2011 for the left line machine, and in December for the right line.

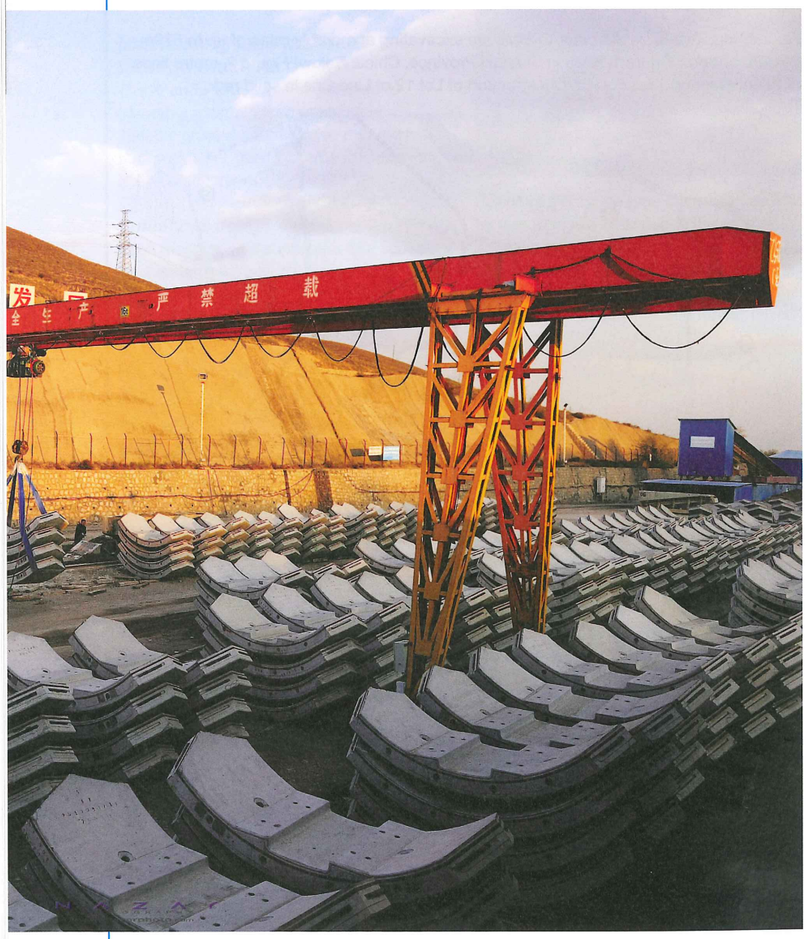
Once online in 2013, Line One will reduce traffic times across the city from well over one hour to 39 minutes. More lines are planned for Xi'an—up to six new routes totaling more than 250km by 2020. The new Line Three broke ground in May 2011, following extensive feasibility studies of the loess layers and fissures along the alignment. The route, expected to be complete in 2015, will run from southwest to northeast through high-traffic areas.

Far left, top: Two 6.2m diameter EPBMs are excavating at monthly rates of up to 579m
Far left, bottom: Figure 1, Xi'an in Shaanxi Province, China; Below: Figure 2, metro lines of Xi'an. Planned lines dotted. Construction of Lot 12 of Line One in solid red



Pinglu's pipe

The latest stage of the Yellow River Diversion Project in China, was undertaken by a single TBM on a long drive through difficult ground conditions, reports Patrick Reynolds



Next month, the Pinglu water transfer tunnel – which was a greater tunnelling challenge than expected due to difficult ground over 25km – is due to go into operation on the Yellow River Diversion Project in China.

Taking more than four years to complete, the excavation took longer than initially envisaged. Overcoming the tough conditions, the Austrian-Chinese joint venture contractor finally holed through with the 4.82m diameter TBM before the end of 2010 to successfully complete the gargantuan undertaking. Since then the final insitu lining works have been underway to complete the project.

Yet, while the excavation of Pinglu tunnel was a major feat, the tube is but a fraction of the colossal 200km-long scheme that has been under construction for more than a decade.

Grand Diversion Scheme

Conceived as a long-term, strategic scheme to share a portion of national water resources, the Yellow River Diversion Project will transfer significant flows to chronically dry regions of Shanxi province. The province has rainfall of only about 400mm per year.

The client for the regional water transfer scheme is Shanxi Province Wanjiazhai Yellow River Project General Corporation.

Early development work on the scheme

Left: Stacked hexagonal, honeycomb segment for tunnel lining *Credit: Nazar-Photography*; Opposite: Figure 1, location map of Pinglu tunnel on Yellow River Diversion Project, China

Pinglu was a tough tunnelling challenge in difficult geology *Credit: Nazar-Photography*

led to a decade of extensive initial construction work that came to a close at the end of the 1990s. More than 100km of conveyance tunnels were constructed to form the General Main and South Main sections of the scheme. Much of the tunnelling and construction work was undertaken by combinations of Italian and local contractors, and employed a number of TBMs, including Robbins machines and an NFM shield.

More recently, the client has focused its development efforts on the North Main Line section, which includes the Pinglu Tunnel connection and also about 15km of tunnels, excavated by drill and blast. The North Main Line will transfer water to the town of Pinglu and cities of Shuozhou and Datong.

Pinglu Tunnel

Austria's Alpine (part of FCC group) undertook the tunnelling work at Pinglu in joint venture with a local partner, together operating as Sino-Austria Hydraulic Engineering Company (SAHEC).

They knew the geology along the alignment would be of unusually mixed strata, from soil and often sticky, medium hard rock, to saturated clay zones and highly abrasive sandstone as well as traces of coal; the project area in Shanxi province has significant coal deposits. To complicate the task further there are also fault zones. In the event, the tunnelling challenge proved to be even greater.

Alpine had a team on site since mid-2005. The JV had decided to excavate the long tunnel through challenging strata using only one TBM, a Robbins double shield which had been used earlier on the scheme. The TBM would only have one intermediate stop on the drive, at a shaft near Daliang, past the half-way point, where refurbishment could be performed before the machine would be relaunched.

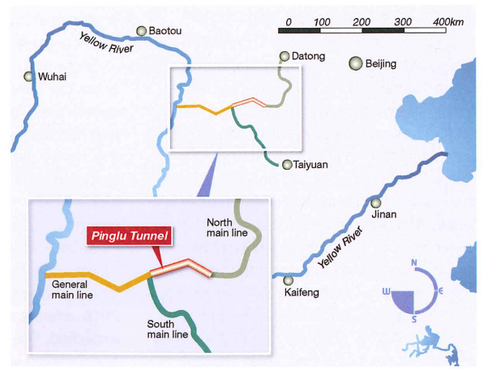
The TBM would build a primary lining of precast concrete rings formed of hexagonal, honeycomb segments. The 4.32m i.d rings would be constructed of four segments in a longitudinally staggered formation. The design was developed to enable rapid, continuous boring with no downtime for segment erection. The secondary lining would be insitu cast concrete to complete the water conveyance tunnel to a finished diameter of 4.14m.

It was anticipated that the construction period would last until early 2009 under the EUR 47M (USD 66.6M) contract. The geological challenges, however, would see the main excavation continue until late 2010.

Alpine Meyreder had worked previously on Lot One of the Yellow River Diversion Project. The works had involved excavation of an intake as well as branch and access tunnels plus shafts and pumping station caverns (165m long by 18m wide by 39m high). The various pumping stations are used to lift the water from Wanjiazhai reservoir on the Yellow River and help overcome head losses from water flowing over long distances.

Excavation

The double-shield was used previously, from 2000, to bore 12km of tunnel on the earlier, Lot Five section of the Yellow River Diversion Project, during which, Robbins reports, it set two world records for machines in the 4-5m diameter class: a best month and monthly average of 1,855m and 1,352m, respectively.



Little adaptation was required to driving Pinglu tunnel as the geology was expected to be of an order that was broadly similar to that of the initial drive. Only refurbishment and maintenance were undertaken on the machine while the back-up system needed to be modified. Having also been used on the previous drive on the scheme, the back-up frame was extended from one to two strokes and so would allow the TBM to maintain good advance rates as journey times lengthened for supplies and spoil removal as the face advanced.

Segment production was undertaken by Alpine at a dedicated yard in Shuozhou, some 15km from the site, and manned by nearly 400 workers. In total, approximately 83,450 hexagonal honeycomb segments were produced to line Pinglu tunnel.

The TBM was launched on Pinglu tunnel in the third quarter of 2006. After two tough years, with often more difficult ground than expected, the machine completed 13km of the drive and holed through into the shaft near Daliang in October 2008. Despite the hard going, the TBM had achieved an average monthly advance rate of 750m.

Alpine's managing director in charge, Siegfried Muller, then described the going as working through 'extremely difficult' ground. In the first section, the TBM had met a number of fault zones and there were also coal seams up to 12m thick.

The opportunity of the breakthrough allowed for a planned stoppage to refurbish the machine, and it was sent on its way again before the close of 2008. It was anticipated that the remaining section, of slightly more than 12km, could be excavated within about 16 months to enable final breakthrough and completion of the primary lining by May 2010.

Some six months into the relaunched drive, the TBM had excavated three-quarters of Pinglu tunnel and the 15,000th ring had been erected. Alpine Bau's head of machinery dept, Paul Bargmann, commented that the TBM had achieved high output "in some very challenging ground conditions".

By then, due to the highly varied geology, it was expected the final leg of the boring would not be over until near the end of 2010, a few months later than previously expected. The geological conditions encountered varied between thick coal seams and clay zones to extremely abrasive rock – sandstone with up to 70 per cent quartzite content.

Above: Double shield completing bore of Pinglu tunnel

Complicating the tunnelling task further were the demands on support to the face as the TBM advanced. In the final few kilometres of the drive the travel time to the face had extended to almost 90 minutes and supply trains were travelling hundreds of kilometres each day. There was also a complicated challenge for the ventilation systems. Yet, over the bore from the Daliang shaft the advance rates were able to reach almost 50 rings (70m) per day.

Bargmann said, "The key to this project's success was the crew. We had the right mix of experienced people and young people hungry to learn."

As per the revised programme, the TBM holed through before the end of the year and since then construction has focused on the cast insitu lining work. The tunnel will be ready shortly for operational use, carrying first diverted flows of the Yellow River to Pinglu and other cities.

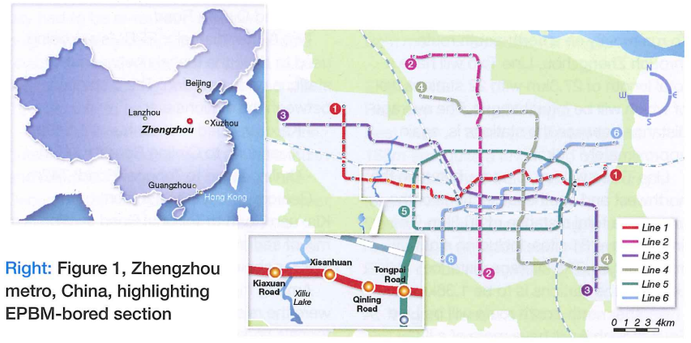
Crossroad metro

A major underground metro development programme is underway in Zhengzhou, central China, which is set to become an even more important city hub in the national rail network, reports Patrick Reynolds

The booming city of Zhengzhou, in Henan province in east central China, was always a strategic crossroads for transport. Economic growth in the country has led to increased development and pressure on transportation systems in the city, which has had no metro but is now embarking on a major capital construction programme.

Located on the Yellow River, Zhengzhou presents an extensive challenge for tunnellers of relatively shallow, soft ground excavation to build a mostly underground, twin bore metro system in the built-up urban area.

A number of TBMs are being deployed on construction of the first phase of Line One of the metro, most of the shields having been manufactured locally. US manufacturer Robbins has supplied two EPBMS, assembled in China, for the west end section of Line One where the shields were launched late last year by the 11th Bureau of the China Railway Construction Corporation (CRCC).



Right: Figure 1, Zhengzhou metro, China, highlighting EPBM-bored section

Growing need in Zhengzhou

As a city of more than seven million people and set to become an even bigger national railway hub, Zhengzhou is a prime candidate for metro construction to help serve the transport needs of the growing population and expanding economy which is already operating with a road network heavily under pressure.

Initial planning for the metro system began a decade ago and the proposals that were drawn up led to a revision of the city master plan. Then, by 2003, the city had a pre-feasibility study for Line One underway.

In parallel, Zhengzhou has been preparing for the national rail transport plans that call for main North-South and East-West routes to run through the city, the former between Beijing and Guangzhou, and the latter between Xuzhou and Lanzhou. To tie-up to these intersecting lines, Zhengzhou will see four main rail links constructed separately to the metro building investment.

Subway development and operations for the city are undertaken by Zhengzhou Metro Company, which plans to construct a network of six lines by 2030. The company was established by the city in 2008. Its transport goal is to have most areas of the city covered and the centre to be accessible within 30-40 minutes of travel.

Zhengzhou metro

The metro network of six lines being planned for Zhengzhou will be developed in three main phases, the first of which is expected to be completed by 2015. However, the services on Line One, which forms a major part of the Phase One development works, are due to commence by around late 2013.

A number of local contractors are working in the different packages of the Phase One works – in addition to 11th Bureau of CRCC there are also the First and 16th, and Beijing Urban Construction Group, Shanghai Tunnel Engineering Company (STEC) and China Railway Tunnel Group, part of China Railway Engineering Corporation (CREC).

There are eight shields presently on Phase One of Line One, mostly manufactured by local firms, such as STEC and also China Railway Tunnel Equipment (via China Railway Tunnel Group it is part of China CREC), and there is the pair of EPBMs from Robbins. Eventually, there are to be a total of 12 TBMs on the first phase of Line One.

The machines are being used on the current, Phase One-only west end of Line One, between Kiaxuan Road and Tongpai Road; the line will be extended later on a route that turns north.

Line One

The route of Line One will run east-west through the heart of the city as part of a network that will have an overall shape that could be approximated to the radiating lines of a star upon which a circle has been imposed – Line Five, eventually.

Line One extends from a depot in the east of the city and runs parallel to a main railway for a short distance then continues west through the city, intersecting the rail line again at a few points as well as future metro lines. At the far west side of the route, Line One turns sharply north. The Phase One works do not include the northward leg.

In Phase One development, approximately 26km section of Line One will be constructed underground in twin bore tubes with a total of 52km of excavated route, including 22 cut and cover stations. The average distance between stations is slightly less than 1.3km. With

this phase of the line's construction to be completed in 2013, the client – Zhengzhou Metro – noted late last year that the underground works were approaching the halfway point.

When fully completed, though, Line One is to have a total length of approximately 35km and 28 stations, including a number of interchanges with all five of the other lines to be developed. The interchange stations will include those at Tongpai Road, Zijingshan, Convention Centre and Yellow River Road.

Other Lines

To run mostly on a north-south route through Zhengzhou, Line Two will have a total length of 27.3km with 22 stations, six of which will be interchanges. The average distance between the stations is, again, approximately 1.3km.

Line Three will run, broadly, between the northwest and southeast sections of the city over a total distance of 40.8km. The line will have 31 sites, including eight interchanges. The average distance between the stations is to be 1.36km.

Another north-south route will be Line Four, though it will have more of a "Z" shape on the metro network map, the extended legs at each end going west and east, respectively. The line will be 34.7km long with 25 sites, seven of which will be interchanges. The distance between stations on this line, at an average of 1.45km, will be the longest on the network.

A circle line in the centre of the metro network will be Line Five. The loop will be 40.6km long with 32 sites and 10 interchanges. The stations will be 1.3km apart, on average.

The last line of the metro network – Line Six – will have a zig-zag route between the south and east quarters of the city. The total length of the line is to be 24.3km with 19 sites, including six interchanges and stations on average 1.35km apart.

To develop this extensive network, Zhengzhou Metro plans for Phase One of construction to focus on the majority of Line One and Two, bringing a total of 45.4km of route into service by 2015.

By 2020, the company plans for Phase Two to complete the first lines and undertake the initial stages of Lines Three and Four. This phase is to add 50.2km to the network, taking the total length to almost 96km.

The third and final phase of the scheme is to add 106.7km of new construction between 2020-30, bringing the total length of the metro network to 202.5km.

Right: Shallow tunnelling is called for on Line One of Zhengzhou metro
Below right: One of the EPBMs on Line One of Zhengzhou metro

The EPBMs

The 11th Bureau of the CRCC is building a 3.6km long stretch of twin bore between Kaixuan Road station in the west end and Tongpai Road in the east, and which a future interchange with Line Five (circle line). The stretch straddles the shallow Xiliu Lake and includes two further, intermediate stations – Xisanhuan (near Third West Ring Road) and Qinling Road.

Two 6.15m diameter EPBMs are being used to drive the tunnels between the stations on the section. The distances between the stations are:

- Kaixuan Road to Xisanhuan: 1,549m
- Xisanhuan to Qinling Road: 1,316m
- Qinling Road to Tongpai Road: 742m

Geology along the alignment of the Kiaxuan Road to Tongpai Road section is a mix of sedimentary strata – clay, fine sand, loess, pebbles and some groundwater.

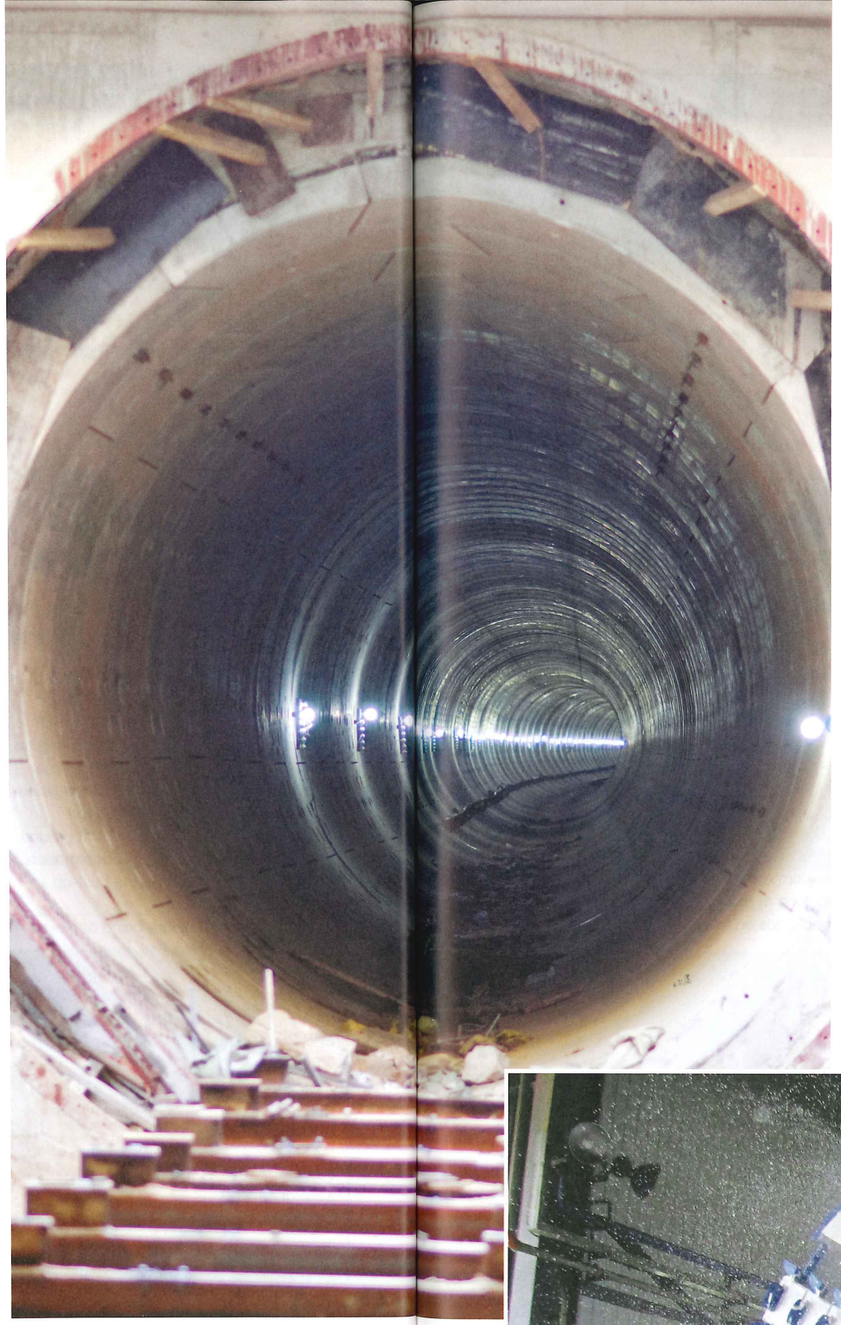
Among the key anticipated challenges were the relatively shallow cover over the tunnels and the consequent delicate excavation work for the shields in the dense urban environment. The cover goes down to approximately 8m for about half of the route, and for the short distance below Xiliu Lake (which is only 1-2m deep) the distance from the tunnel to the bed is only 7m. In sections, the alignment passes below building foundations and a major road bridge.

The machines have a maximum thrust of 36,000kN, maximum torque of 4,785kNm, cutterhead speed of up to 2rpm and maximum stroke of 1.95m. The cutterheads have 750kW electric, variable speed motors, and are fitted with tungsten carbide knife-edge tools. Spoil removal is via a 800mm diameter shaft screw conveyor. The shields have two-chamber type manlocks.

The shields were assembled in Chengdu, at the facilities of Chengdu CSR Tunnelling Equipment Company. Components were brought from Japan (main bearing, main seal), US (electrical and hydraulic systems), Germany (transducers) and, locally (machine shield, cutterhead, backup gantries and additional equipment).

To reduce settlement, foam and bentonite are being injected for soil conditioning during the drives, and there is tight monitoring of both advance rates and volume of spoil being generated by the advancing drives.

The reinforced concrete lining is formed in 1.5m long rings (five plus one) built with 300mm thick segments. To prevent segment deformation, active articulation is employed in curvatures down to 200m radii. Standard cement mortar backfill is used to grout behind the rings.



Shield progress

The TBMs are being used by the Chinese contractor parallel bores that began in October 2010 and, following some waiting for station completion as well as relaunches plus dismantling, transport and reassembly, the drives were expected to be finished as *T&TI* went to press.

The first shield that was launched – EPB345 – set off from Xisanhuan, an intermediate station, on its eastward drive late last year and was followed three weeks later by its sister machine, EPB346. The contractor focused on getting the stretch between Xisanhuan and Tongpai Road constructed and then would return to relaunch the machines in the other direction to Kiaxuan Road station, which had not been excavated at the outset.

Kiaxuan Road was unable to accommodate the start of tunnelling eastwards as a main water supply pipeline feeding residential areas in the west of the city had to be re-routed. Those works are only now being completed, which should enable the excavation of the station to be finished. The last leg of the tunnelling will then be able to be finished.

To commence tunnelling, though, at the outset the TBMs advanced from Xisanhuan and reached Qinling Road station in late December 2010 and early January this year, respectively. At each breakthrough the machines met the project's standard rebar strips, arranged vertically in the walls at the portals and had to be cut away.

Following some brief maintenance, EPB345 was relaunched from Qinling Road a week after the arrival of the other shield which was itself subsequently sent boring again a month later. The machines reached Tongpai Road in early March and early April, respectively.

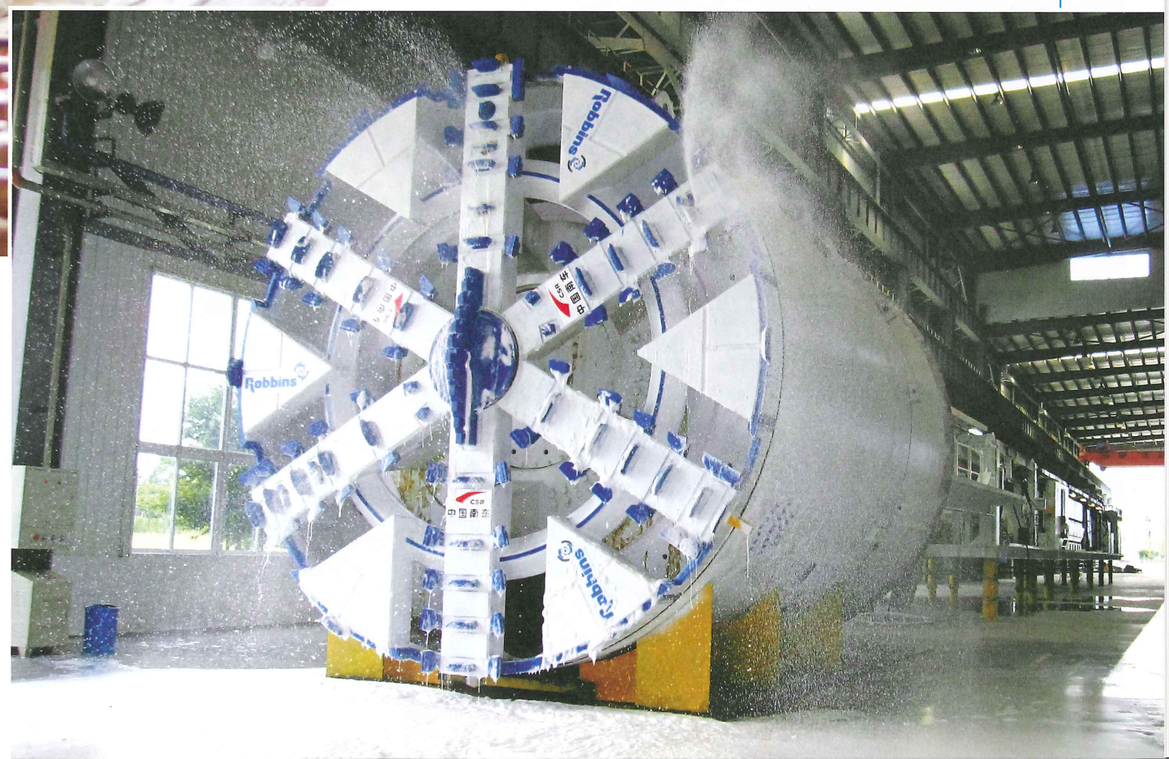
"The breakthroughs went perfectly," said CRCC 11th Bureau's general mechanical and electrical engineer on the project, Zhou Shuqing. "Machine downtime during tunnelling has been very minimal, and the organisation of this project has been very good."

The crews on each machine work in two 10-hour shifts per day. The best advance rates on completing the first two sections to Tongpai Road were:

EPBM 345:
Best day = 31.5m (21 rings);
Best week = 201m (134 rings); closest 176m and then many in 140m-150m range.
Best month = 601.5m (401 rings).

EPBM 346:
Best day = 34.5m (23 rings);
Best week = 189m (126 rings); closest 183m and quite a few in two bands, the 162m-182m and the 100m-125m ranges, respectively.
Best month = 720m (480 rings); a project record by then, and also for a 6m-7m EPBM on Chinese projects, says Robbins

At Tongpai Road the TBMs were extracted and transported back to Xisanhuan station for reassembly and relaunch, this time westward, towards Kiaxuan Road. Most recently, EPB345 has gone as far as it can at present and, with 645m left to bore, is holding for Kiaxuan Road to be fully excavated before it can proceed. Its sister



Left: The TBMs were assembled in Chengdu, China
Below: Zhengzhou is developing a major underground metro network

shield is a short distance behind.

On this last leg, though, these EPBMs have passed below Xiliu Lake, below which the ground was found to consist of very permeable soils, and the groundwater is connected to and fed by the lake due to vertical leakage. Before proceeding through this section of the drives the systems of the TBMs were re-checked and the tailgate brushes changed. During excavation, each shield kept tightly to restricted parameters – maintaining earth pressure at 1.1bar-1.3bar, the cutterhead speed to 1rpm and the advance rate to only 30mm/min-40mm/min.

With the final station in the section almost ready and the drives set to resume shortly, it is expected that the EPBMs will hole through by late October as *T&TI* went to press. Afterwards there is the potential for further use of the machines on the metro as they are reported to have performed well and the contractor is looking at procurement underway for other packages on the scheme.

Send in the divers

The expertise, ingenuity and bravery of commercial divers working with tunnels is unsurpassed. The services of divers can be called upon during normal operations as well as emergency situations, with each task placing its own demands on men and equipment. Maurice Jones, with Nicole Robinson, has been checking up on what is needed and why

While most tunnellers are at least aware of 'compressed air working' in tunnelling, the related activity of diving seems to be outside the scope of the activities of most. This may be because diving teams are called in to perform a specific task, which they usually get on with in isolation, having minimal interaction with others in the tunnelling workforce.

However, diving has been associated with tunnelling ever since Marc Brunel lowered a diving bell into the River Thames in efforts to repair breeches in his Thames Tunnel at Rotherhithe; the world's first tunnel under navigable water. Also in the Victorian era, lead diver Alexander Lambert working for contractor Thomas Walker entered the flooded Severn Tunnel in 1880 between Wales and England to help seal off the tunnel from persistent inflow from The Great Spring during construction. The work was completed in 1881, although flooding returned later and Lambert was called upon again. He used the newly developed Henry Fluess' self-contained breathing apparatus instead of surface-fed air, the hoses of which became entangled as he entered through a shaft and walked 300m to close a watertight door and valves. A refined version of the self-contained underwater breathing apparatus (SCUBA) is still in use.

Divers are an elite, or should be, who have earned their position through intensive training, fitness, specialist knowledge and not a little courage. In fact, in many countries specific training to satisfy regulatory authorities. Divers also need to have regular and thorough medical examinations to check on fitness for their tasks, and in most cases to administer vaccinations against diseases such as hepatitis that may be acquired from contaminated water

Although the uses for diving may have reduced in tunnelling over recent years, where they are needed they are essential, whether it is a planned activity in the project or to get the project out of difficulties. There are also roles to play in certain existing tunnels for inspection and maintenance.

Applications

One of the most common uses for divers in tunnelling was for work around the entry, and perhaps exit points for TBMs with shafts under groundwater. It is often more practical and safer to let a shaft flood and use divers to carry out steel cutting, welding and alignment work to clear the way for a TBM to pass through the lining.

In recent times such work has become less necessary both due to more accurate guidance and monitoring of TBMs, minimising cases of misalignment, and the advent of various designs of 'soft-eye' in tunnel linings that allow the TBM to cut its way into or from the shaft without allowing any major leakage of groundwater into the shaft. One exception was by Bekk Solutions (BSL) divers in Hunghom, Hong Kong, where they performed underwater welding, burning and grouting in the flooded reception shaft to recover a TBM. Bekk uses surface-supplied mixed gas diving procedures as well as more conventional approaches. Flooded TBMs have also been recovered using compressed air working in difficult ground conditions (see feature, page 54).

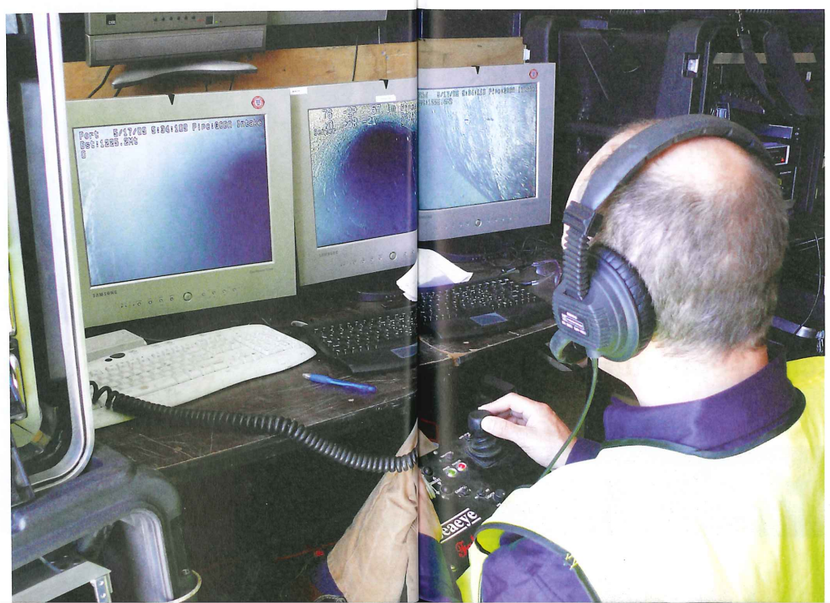
Immersed tube

Another situation in which water is a tool as well as a hindrance is in tunnel construction by immersed tube. The use of waterproof CCTV and digital imaging greatly simplifies the supervision of installation operations underwater, such as for dredging, lowering segments into position, and adjustments. However, there are many tasks requiring close inspection and handling duties such as checking seals and repositioning pumps.

One immersed tube operation that placed particular demands on diving was of the first tube segment of the new Amsterdam Nord-Zuid metro line including a crossing of the River Ij in immersed tube. (See *T&TI* October 2011 pages 30-37.)

One of the divers on the intricate, and possibly unique operation by Strukton, Van Oord and Heijmans to place an immersed tube section under the Amsterdam Centraalstation is Martin Sitsen. He started commercial diving in harbour caisson work in 2006, and is also a hyperbaric lock attendant. His current underwater work, associated with placing the tube section in the Zinc slot, as it is known, includes high-pressure grout removal, cutting through old wooden piles with a chainsaw, and various metal cutting and welding jobs. He reports that visibility is fairly limited (about 16m), but he prefers the work near his home rather than the long periods away on previous North Sea oil and gas diving work.

Such has been the battle with the North Sea in Europe, particularly in the Netherlands, Belgium and west Germany that a great deal of expertise has been built up both for diving and other related hyperbaric activities. In the Netherlands in particular the invariable use of immersed tube tunnel technology until recently has involved diving and dredging work for placement and connection of segments.



Right: **Seaview Systems control centre used in the inspection of the GCDA desalination plant intake tunnel, Australia**

Tunnel inspection

Ideally water tunnels should be inspected and maintained while dry, but for operational reasons this is not always practical and diving has to be adopted. The New York water supply system has had a long history of difficulties, frequently needing underwater inspection and maintenance. One such campaign started in 2008 when Global Diving & Salvage of Seattle was called in to repair a valve for the Roundout Contractors JV on the 73km-long Roundout-West Branch tunnel from the Catskill Mountains reservoirs. This necessitated diving saturation techniques, similar to those in extreme hyperbaric tunnelling, using a breathing mixture of around 97.5 per cent helium and 2.5 per cent oxygen to work in over 200m of water. Prior to the work it was necessary for Global to demonstrate to the client that its divers could carry out the necessary tasks within an immersed mock-up layout in Seattle. The equipment required non-destructive testing, including underwater cutting welding and drilling equipment. Various tasks meant that the diving team have been engaged there until this year.

The team of six divers required a total global team of 32 to support them with life-support control, food and drink, and special reading material. Various necessary goods were passed through a materials airlock into the saturation living chamber that also included showers, a television and a basketball hoop. The diving teams live in the chamber for a month at a time leaving only to enter the diving bell for work, or to leave after decompression at the end of their stint. For work the diving bell was lowered with three divers to the work site for a 12-hour shift with each man taking a four-hour turn to work, including partial demolition to gain access to replace valves.

Equipment

Due to the complexity of many diving requirements and the need to ensure safety, any assembly of diving equipment is likely to contain many parts that will need to work together. Functions will include a portable or mobile air compressor with filtered air discharge, air tanks and back up system, full instrumentation for pressures and air/gas supply, communications to all parties, video systems, testing equipment, sufficient tubes and cables, diving suits to cope with the expected conditions, diving helmets, weights, gloves to suit the work to be performed, and the tools required such as underwater cutting and welding equipment, hydraulic power saw.

There are well-known suppliers of such equipment. Draeger, well known in tunnelling for gas detection and rescue equipment, supplies a full range of diving equipment including compressors and diving helmets. Another well-known make of diving helmet is Kirby Morgan.

The unusual

Diving teams have to be prepared to tackle the unusual, and this may not even mean going under or into water. They are just deemed the best people for the job. In the aftermath of the New York World Trade Center (WTC) attack divers were sent to wade through water in a 1,500ft (460m) tunnel to reach the PATH station below the WTC where siphon pipes were installed to remove the flooding. Among the hazards that might be expected were excess carbon monoxide and high temperatures.

Another unusual task that ended tragically was when five men were sent into the new 9.5-mile (15.2km) long sea outfall tunnel from Boston's Deer Island sewage treatment plant in 1999 to remove safety plugs to allow connection to the sea and let the tunnel become 'live'. Although the tunnel was relatively dry, diving techniques still had to be employed, as there was no ventilation in the tunnel and minimal oxygen. Equipment was carried in using two Humvee rough-terrain vehicles and a trailer. As the tunnel got narrower the team split, three advancing on foot and two remaining with the Humvee as back-up. The two back-up divers suffocated due to faulty prototype breathing equipment.

While this incident is now old it still holds many lessons, including the importance of thoroughly testing all equipment and procedures before use, the dangers of long distances without proper communications, and the need to resist the pressures from project delays and finance when such difficult procedures and unusual procedures are being undertaken. No similar work has been attempted since, but use of double or triple breathing supplies is now common.

Unmanned inspection

One approach to increase safety is to remove divers altogether from the necessary task, if this is possible. The equipment was originally developed for deep-sea work without exposing divers, but some flooded tunnel inspections lend themselves to this work. A leading supplier, Seaview Systems of Michigan, subcontracting to ROV Downunder, completed Australia's longest tunnel penetration at 2.2km for the sea intake. The work was for as-built investigations of the intake and outlet tunnel for the Gold Coast desalination plant, which the Gold Coast Desalination Alliance, a JV of John Holland, Veolia Water, Sinclair Knight Mertz and Cardno, constructed for the WaterSecure authority of Queensland's government.

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Modern compressed air and gas work

Work in compressed air has its origins in the early-to-mid 19th century. It is relatively uncommon these days and consequently few tunnellers have had experience of current practice. Donald Lamont of Hyperbaric & Tunnel Safety reviews its development, current practice and its context in tunnelling

Compressed air environments are used in shaft sinking and tunnelling as a means of controlling water ingress and hence ground stability. A working chamber is formed by installing an airdeck or bulkhead in the shaft or tunnel after which compressed air is injected to pressurise the space between the airdeck and the shaft invert, or between the bulkhead and tunnel face. Access through the airdeck or bulkhead is by means of airlocks. In contemporary tunnelling the bulkhead is most likely to be part of the structure of a TBM cutterhead.

The main health and safety risks are decompression illness following the return to normal atmospheric pressure, and fire due to the enhanced mass concentration of oxygen in the pressurised atmosphere.

Air pressures of up to around 3.5 bar, equivalent to 35m of water head, are permitted by health and safety legislation in most countries. Pressure limits have not changed over many decades, and probably reflect the capability of early compressors to produce reliable supplies of compressed air that were relatively free of contaminants and the requirements and state of knowledge of the tunnelling industry at the time.

Advances in medical technology in other areas of hyperbaric medicine are being introduced to tunnelling to reduce health risks associated with decompression.

The current UK legislation regulating compressed air work is the Work in Compressed Air Regulations 1996 supplemented by Health and Safety Executive guidance document L96 - 'A guide to the Work in Compressed Air Regulations 1996' along with the addendum to L96 covering oxygen decompression and the use of non-air breathing mixtures. L96 is complemented by guidance in BS 6164:2011 – 'Code of practice for health and safety in tunnelling in the construction industry', which has a clause dealing specifically with the interaction between the pressurised workings and the surrounding ground. Within Europe, EN 12110 – 'Tunnelling machinery – safety – Airlocks' is the relevant standard for the manufacture of bulkheads and airlocks.

Right: A medical lock attendant managing airlock entry [Photo: Tony Ridley Hyperbaric]

Shaft sinking

In the past, shafts were sunk using underpinning techniques or as caissons. Compressed air was sometimes required to control water ingress to enable the underpinning to continue below the water table. In caisson sinking, compressed air allowed men in the working chamber below the water table to remove spoil from the base of the caisson which in turn allowed the caisson to sink in a controlled fashion. The most recent large caisson to be sunk in the UK utilising compressed air was that at Ramsden Dock in Barrow-in-Furness in 1991. The 25m by 25m concrete monolith formed the basic structure of a new dock entrance, which allowed the passage of nuclear submarines from the nearby shipyard where they were built to the open sea.

Also in shaft work compressed air is sometimes required to counter water ingress when forming the tunnel eye during the launch of a TBM. A recent example of this application was in Belfast where it was used on a tunnel sewer contract.

Underpinned shafts are now more likely to be constructed using sprayed concrete lining (SCL) lining techniques than precast concrete segments. With the availability of slurry wall techniques having the capability to form shaft walls to depths of around 100m in water bearing ground, the use of compressed air for caisson sinking has all but ceased.

Tunnelling

Historically, compressed air was used to facilitate the excavation by hand and/or open shield of tunnels in soft ground below the water table. Bulkheads to form the airlocks were usually installed in the tunnel lining, close to the shaft bottom and the whole tunnel pressurised with air. As the whole tunnel was 'under air', there were large numbers of exposures to pressure.

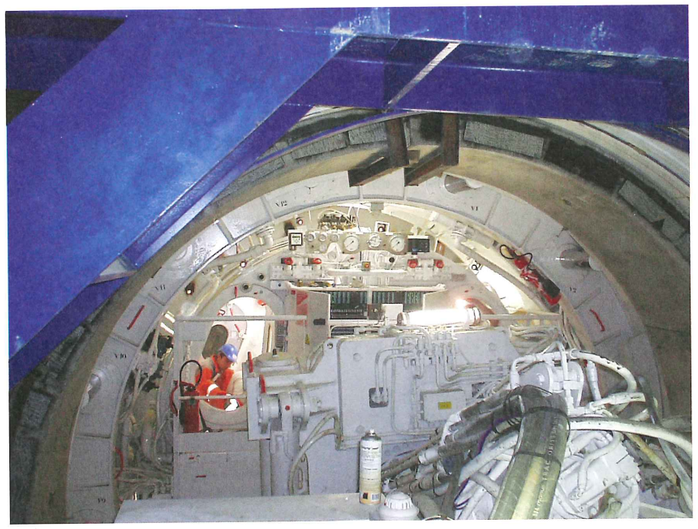
Over recent decades the development of sophisticated TBMs for soft ground tunnelling – slurry TBMs, EPBMs and their variants – has done away with the need for pressurising the whole tunnel. Some exposures to compressed air are still required for cutterhead inspections, tool replacement and other interventions in the cutterhead of the TBM. Typically however, the use of TBMs has reduced the number of exposures by two or three orders of magnitude. On very large TBMs it is now possible to change cutters at atmospheric pressure from within the spokes of the cutterhead itself.

Although the majority of compressed air working is now associated with TBM drives it should be remembered that compressed air still has a role in responding to the unforeseen circumstances which make tunnelling the challenge that many in the industry enjoy. Ground stabilisation to enable the replacement of a broken pipe in an undersea pipejack or insitu repairs to a damaged TBM cutterhead are only two examples of where compressed air can still be required.

Exposure to pressure in tunnelling has led to numerous cases of decompression illness (DCI). Over the past 60 years for which UK records exist, around 0.6 per cent of all exposures have resulted in DCI. This is an average figure which does not reflect the true nature of the problem. Not surprisingly, detailed analysis of the DCI figures has shown that those most likely to experience DCI are the miners. It was not unusual for between a quarter and half of the miners on a contract to experience at least one DCI 'hit'.

The predominant manifestation of DCI in tunnelling is Type One decompression sickness or 'the Bends', as it is often referred to. This occurs in over 90 per cent of tunnelling DCI cases. Although often considered to be a 'hazard of the job', and of little consequence, decompression sickness resulted in occasional fatalities throughout the 20th century until the introduction of the Blackpool tables of exposure limits and decompression times in the mid-1960s. Fortunately Type Two DCS, which results in severe neurological symptoms, is relatively rare from tunnelling exposures.

By the mid-1960s chronic DCI (dysbaric, also known as aseptic, osteonecrosis) had been identified. This is a degenerative and ultimately crippling disease affecting particularly the hip joints. There is no cure for osteonecrosis and the only treatment is surgical replacement of the bone ends or joints. To aid early diagnosis of osteonecrosis, everyone working in compressed air at pressures above one bar, had to undergo regular long-bone X-rays. Research in the mid 1990s showed that the strongest correlation for factors resulting in osteonecrosis was a previous Type One DCS event. This finding significantly altered the perspective on the seriousness of Type One DCS.



Above: **Looking through a Bessac TBM being prepared for work on the Toulouse Metro to a technician in the airlock**
Below right: **View from the front of a Brightwater Project TBM to the pressure chamber [Photo: Dr Edmund Kay, Health Force Partners]**

Not only has the reduction in the number of exposures led to significant reductions in the number of cases of DCI, and hence Type One DCS, but the use of oxygen breathing during the latter stages of decompression, introduced in the UK in 2001, is now a routine procedure intended to further reduce the incidence of DCI.

Legislation and standards

At present, there are no planned changes to the UK Work in Compressed Air Regulations. The HSE guidance has been revised and awaits publication. However the perception that official publications are a burden on business has led the current government to impose a moratorium on publishing guidance, including L96.

The revised text of L96, once published, will incorporate a number of changes from the current version. The most significant change in working practice to be accommodated is that compressed air working now tends to be intermittent in nature. Head inspections and tool changes are carried out at intervals of days or weeks. It is not cost effective to maintain lock attendants and medical lock attendants permanently on site. Likewise compressors can be hired in when needed. This has led to the introduction of the role of hyperbaric supervisor – a person in day to day control of the compressed air operation with responsibility to bring together the personnel and equipment required to undertake the compressed air work as and when it is required. A further change, although not imposed by the regulator, has been to merge the roles of lock attendant and medical lock attendant. This leads to greater flexibility by having a small pool of lock attendants on site who can take on either role as required.

Another major change set out in the revised L96 is the use of magnetic resonance imaging (MRI) in preference to x-ray as the means of detecting bone necrosis. This change results from medical safety legislation prohibiting the unnecessary use of X-ray when other means of scanning are available. Unfortunately unlike with X-ray, there is currently no recognised correlation between abnormalities detected by MRI and dysbaric osteonecrosis. MRI is considered to be a more sensitive technique than X-ray so a number of false positive results can be expected. It is likely that X-ray will be required to confirm, or otherwise, the results of the MRI.

The revision of L96 has also given the opportunity to regularise the use of Doppler monitoring as a means of assessing in real time, the effectiveness of the decompression regime being used. Doppler techniques are routinely used in a number of medical applications but have only recently been introduced in tunnelling. Although a group of persons after decompression may not exhibit any overt symptoms of DCI, the quantity of inert gas bubbles in their blood can still be unacceptably high. Doppler monitoring is able to detect this and whilst it cannot be relied upon to identify individuals requiring prophylactic recompression, the Doppler results can allow the contract medical adviser to act proactively to prohibit exposures resulting in an unacceptably high risk of DCI.

BS 6164 'Code of Practice for health and safety in tunnelling in the construction industry' has recently been revised and the most recent edition was published in July this year. Clause 11 of BS 6164 still deals with compressed air working. It provides extensive guidance on the interaction between the pressurised structure and the ground in which it is being built and, in this respect, it very much complements the HSE guidance. Otherwise BS 6164 covers a wide range of topics but not in the level of detail in L96.

EN 12110 is also being revised. The majority of the work has been completed and the revised text should be published in 2012. In addition to a general editorial revision of the text, a small number of technical changes have been made. These include consolidation of the requirements for fire fighting, clarification of the requirements for electrical power supply, an increase in minimum lock diameter from 1.5 to 1.6m and more extensive requirements for the oxygen breathing system.

Unlike L96, ENs are not UK government departmental guidance. However, as they are European Standards, the British Standards Institution (BSI) is obliged to introduce an EN into the UK as a dual-numbered BS EN within six months of the EN being listed in the EU 'Official Journal'.

HPCA

Perhaps the most important development in compressed air working practice currently is so-called 'high pressure compressed air (HPCA) work'. This involves the use of higher exposure pressures than currently permitted by the legislation in most countries. At such pressures whilst pressurisation of the working chamber and manlocks is by compressed air, it is not desirable to breathe that air due to the adverse response by the body to high pressure nitrogen and oxygen. Consequently a major difference between HPCA work and conventional compressed air work is that HPCA requires the use of non-air breathing mixtures, and in some circumstances the use of 'saturation' techniques. Typical breathing mixtures are oxygen and helium blends (heliox) or oxygen, nitrogen and helium mixtures usually known as 'trimix'. Breathing mixtures are supplied by line-fed mask. Exposure to excessively high oxygen pressures leads to lung degeneration and other adverse health effects. High pressure nitrogen is both more difficult to breathe due to its density and is narcotic. Helium, whilst expensive, acts as an inert and low density diluent.

Saturation techniques are commonplace in offshore diving and those concerned live for periods of up to 28 days under pressure with a single decompression at the end of that period. The decision whether saturation is required or not in HPCA work is based on the exposure pressure and the amount of work to be done. For pressures of up to around six bar, non-saturation exposures can be the more cost effective. At these pressures, exposure periods of between 30 and 45 minutes are possible within the recommended limits on decompression time and total exposure time. Where the work to be done under pressure requires longer exposures or higher pressures then saturation techniques will be required.

Saturation techniques require significant resources in equipment and personnel. A living complex on the surface is required along with the means to transfer the compressed air workers under pressure between the living complex and the TBM. In addition to the normal lock attendants in the tunnel, life support personnel are required to look after those in the living complex. Fortunately some equipment, personnel and knowhow are available from the offshore diving industry. There is likely to be continuing debate about whether divers or tunnel workers should be chosen for HPCA work but probably a team formed from a combination of both is the optimum available solution.

Not surprisingly HPCA work involves considerable health and safety risks. DCI, fire and the prevention of sudden decompression as a result of a blowout are some of the more obvious.

A number of tunnel projects around the world are being constructed in situations where high water pressures can be anticipated. Amongst these is the Lee Tunnel in London, which will be constructed at around 60 to 70m below ground. This means that the theoretical maximum air pressures could be as high as six or seven bar, and should entry under compressed air be required at these pressures, HPCA techniques will be required.

Meeting challenges under pressure

Traditional compressed air work in tunnelling, also referred to in some quarters as caisson work and diving, has all but disappeared in modern tunnelling, but new challenges have been thrown up by deeper tunnels and those of larger section. These are being taken up by sophisticated procedures to ensure the safety of those involved in necessary work. Maurice Jones reviews some leading practitioners and their tunnelling work and equipment. Additional material from Nicole Robinson

Today, typical compressed air work, or hyperbaric intervention as it is perhaps more accurately termed, is concerned mainly with changing TBMs cutters and other maintenance tasks on the cutterhead or in the TBM pressure chamber. Working pressures are usually kept below 3.5bar, which is the maximum allowed by normal compressed air regulations in most countries. This is usually achieved by the planning of the tunnel alignment in appropriate strata, groundwater lowering, or other exclusion techniques such as grouting or ground freezing.

Other common requirements for a hyperbaric working atmosphere include the rescue of TBMs stuck in ground under a water table, repair of failed tunnel linings in similar circumstances or, sometimes, shaft sinking through an aquifer. In addition to the health and safety considerations of the pressurised atmosphere, related enhanced hazards such as fire potential and heavy handling in small spaces must also be properly considered.

The deeper tunnels go, the more difficult it becomes to avoid higher groundwater pressures when face work becomes necessary. Also, as tunnelling always has a chance of nasty surprises, there need to be methods and equipment available to tackle circumstances such as trapped or stuck TBMs, and failures of the tunnel support lining or waterproofing.

In the limited, but seemingly increasing, circumstances requiring intervention at pressures above 3.5 bar, saturation diving techniques (see p.48) come into play. The techniques involving not only higher pressures but also non-air breathing mixtures, long periods immersed under pressure, and intense medical and fitness supervision, have been developed mainly through deep-sea diving.

Advanced thinking

As with many other contingency procedures to do with tunnelling, contractors and maybe clients have a natural tendency to want to save money when something might never happen. Whereas cutter changing interventions can be planned in advance on long drives, they may be a surprise on shorter tunnels with higher than expected wear rates. The expected and actual groundwater pressures and flows are critical.

"We would like to get across the message," says Tony Ridley, managing director of Tony Ridley Hyperbaric Associates, "that the possible need for hyperbaric intervention in a tunnelling project should be assessed at the tender stage. The tender documents should explain what may need to be put into place so that the successful contractor is aware of this and the potential consequences of avoiding or not doing it."

There are a number of centres of expertise in hyperbaric work for tunnelling around the world including tunnelling and medical consultants, equipment manufacturers, equipment rental companies and the provision of specialist operatives and on site lock and chamber attendants, so lack of qualified support for a project should not be a problem so long as the geotechnical criteria for the operations are known as well as possible.

One of Specialist Plant's particular specialities is the supply and installation of a wide variety of airlocks, chambers and other hyperbaric equipment throughout UK tunnelling projects, including Morgan Est's recent work in repairing the Lovat TBMs on the new Belfast sewers where shaft 'soft eye' construction was also carried out under compressed air, plus projects in France, Singapore and Taiwan. Specialist Plant director Ian Matthews explained the company's assurance service. "More often than not hyperbaric equipment is ordered as insurance by a contractor in case access is required into a TBM head under pressure to carry out repairs. Sometimes the equipment is delivered to site and stored there awaiting possible use. In other cases the equipment is prepared and held at the depot for the duration of the contract, reserved for call off by the contractor."

Who does what

There is a recurring debate about who should actually carry out the necessary work under hyperbaric conditions. Ideally the tunnel operative should be trained to the fullest in both tunnelling work and hyperbaric techniques. This is not always possible, and considerations must also include adequate fitness as well as training. In saturation work the extra demands of the procedures indicate that hyperbaric training has to come first, although skills to meet the tasks such as cutting and welding will also be required. Clear instructions on what is required of the diver will need to be given, aided by good communications including CCTV if possible.

At pressures below 3.5 bar there are good arguments for both 'miners' and 'divers'. Former HM Inspector of Health & Safety, Donald Lamont of Hyperbaric & Tunnel Safety (see page 51) favours tunnelling miners to be trained in compressed air work. "They have the skills and expertise required to carry out work required," he says. "You can't expect a diver to be able to excavate a failed lining safely and replace the support, even if it is under compressed air."

Ridley agrees, "I believe that, in most circumstances, where possible existing miners/tunnellers should be trained in the appropriate high pressure working techniques rather than bringing in divers. Divers do not, normally, have an intimate knowledge of the work tasks and safety aspects in tunnelling/TBM applications generally, and particularly not those associated with cutterheads and exposed faces. However, in some scenarios, diving personnel may be beneficial as part of an intervention team when they have previous experience of similar techniques."

Providers of hyperbaric intervention teams and equipment understandably think otherwise. Andrew Hickox of Bekk Solutions (BSL) headquartered in Hong Kong and with bases in India, Sabah, Singapore and the UAE, believes fitness rather than skills is the key, and that means regular hyperbaric operatives. "We feel that divers are best equipped to carry out this type of work. They are generally more physically and mentally prepared to work in the arduous conditions," he says.

Equipment and regulations

While there is enough equipment available, such as hyperbaric chambers, airlocks and pressure management systems available around the world, especially if diving industry suppliers are taken into consideration, ensuring that the equipment meets the particular requirements of tunnelling and local regulations is not always so easy.

"We sometimes get called in by TBM suppliers or tunnel contractors to ensure that the airlocks provided within the TBM meet the relevant standards," says Ridley. "This can also involve good ergonomic, safety and common sense necessitating modifications to the hyperbaric equipment proposed or supplied."

"Unfortunately we can also be called in too late, after a problem occurs or because it is discovered that what provision is necessary is not in place. This may be because the main equipment, or TBM, supplier has been 'economical' in compliance with the relevant standards and good hyperbaric practice. Also, relevant equipment and airlocks are often brought in after a requirement has been identified instead of in advance. This, together with installation, mobilisation, training and medical requirements, causes project delays unless planned beforehand."

Above: The DART (Diver Attendant Recompression Transportable) chamber arrives at the TBM back-up on the Brightwater project (Photo: Edmond Kay); Below left: Inside a 1.8m-diameter decompression airlock equipped for oxygen breathing (Photo: Specialist Plant)

Even the regulations are fallible as they often take considerable time to keep up with advancing technology or are not, for various reasons, adopted by the relevant authorities. As far as the US is concerned, Gerry East of Global Diving & Salvage points out that that country's OSHA compressed air regulations (including decompression tables) are antiquated in that they were made before the advent of modern TBMs and hyperbarics, but they still apply. Contractors must get a 'variance' to not follow any of the OSHA standards. He says, "Many states have adopted their own occupational safety and health plan, but they must adopt standards identical to, or at least as effective as federal standards.

Eastern make-up

BSL is a leading provider of hyperbaric services and other subcontracted specialist tunnel construction services. The Government of Hong Kong approves both the 'Blackpool' Tables and French tables for operating pressures, work and decompression times, and Bekk says it can work with both.

The nature of the ground that has to be tackled in Hong Kong, with a high proportion of made ground or fill, means that tunnelling can be even more unpredictable. Consequently Bekk's work has included a higher than usual proportion of TBM 'rescues' under compressed air. These have included recovery work for China Harbour & Engineering Company on the DSD Drainage contract in Wo Che, Hong Kong. Hickox says, "The rescue work we have carried out has generally been in

front of the shield to remove steel obstructions. This can be quite dangerous in HK as most of the ground is reclaimed. This makes it very difficult to maintain a constant pressure, and there is always the constant threat of total ground failure."

Other work includes more standard interventions for cutter changes. Currently the company is working on compressed air intervention for Chun Wo Construction on the Wan Chai Project, and was recently awarded a contract to support hyperbaric tunnelling operations for Penta-Ocean Construction and Kane Tunnelling on the MTRC XRL Contract 825 for the 2.19-km twin tunnels between Mai Po and Ngau Tam Mei for the high-speed rail link to Shanghai. Bekk's work includes interventions on the two Herrenknecht TBMs being supplied for the project.

Bekk Solutions has not needed to engage in saturation techniques, although teams have worked with surface-fed breathing systems with mixed gas supplies for working at depth. It's equipment, such as chambers, compressors and gas storage is supplied by Unique Systems of Dubai of the Unique Maritime Group, who recently acquired Hydra Marine.

Westerschelde

One of the most significant interventions of recent times was a series necessary for one of the two Herrenknecht TBMs forming the Westerschelde twin highway bores under the River Scheldt southern Netherlands. A paper (le Pechon et al below) describes what was involved including experts from JCLP Hyperbarie, Paris, Leiden University (Netherlands) and Arbo Hypercon (Netherlands). The very high pressure at the face (up to 6.9 bar) was largely unexpected and caused difficulties with the shield itself as well as necessary cutter changes, made worse by the need to work in the bentonite slurry.

Nordseetaucher performed the saturation interventions necessary. As a result of the project demands, this was the first time that saturation technology and mixed gas breathing were used in tunnelling operations. The divers had to be transferred by a 4 bar pressurised mobile chamber using breathing air from their accommodation, where the atmosphere was also at 4 bar pressure using Trimix gas (helium, nitrogen and oxygen).

Trimix was also used when working at the 6.9 bar face pressure. The diving team on each intervention numbered three, with some 37 excursions made outside the habitat chamber, giving a total working diving time of 400 hours.

Brightwater

Necessary repairs to the Herrenknecht slurry-shield cutterheads on the Brightwater Conveyance System sewerage project near Seattle also required hyperbaric intervention, although, at first the necessary pressure was reduced by pumping to lower the groundwater head to atmospheric pressure up to one bar instead of five bar. Hyperbaric facilities had been planned from the start however.

The project is featured in the lecture by Edmund Kay, 'Deep Hyperbaric Tunnelling – Experience with 600 Interventions' as Kay is project physician for the four hyperbaric tunnels operating at up to 8 bar. The lecture also describes the DART, or diver attendant recompression transportable module, the use of oxygen self-rescuer units, the new Biopak 240 Revolution lightweight self-contained rebreathing apparatus and the medical conditions that may be associated with hyperbaric work. Kay is medical director of the Divers Institute of Technology in Seattle and director of hyperbaric medicine at HealthForce Partners, also of Seattle, engaged in workplace medicine.

Lake Mead

An example of the increasing number of saturation projects due to deeper tunnelling, interventions at the Lake Mead Number Three Intake, Nevada, US, are being carried out by Ballard Diving & Salvage, another of the cluster of diving specialist headquartered in Washington state/ Vancouver, Canada.

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Soil conditioning for clays in EPBMs – part two

In the second part of this paper, commenced in the October 2011 issue of *T&TI*, the authors further explain the mechanisms in clayey soil and machinery interactions and the testing of means of reducing adhesion

The authors

The four authors are all associated with the RWTH Aachen University, Germany.

Giovanni Spagnoli, project engineer with Fugro Consult in Plungstadt, Germany, was formerly with the Department of Engineering Geology and Hydrology, RWTH Aachen University;

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Helge Stanjek leads Clay and Interface Mineralogy at RWTH Aachen University;

Rafig Azzam is also with the Department of Engineering Geology and Hydrology at RWTH Aachen University.

One mechanism in the behaviour of clayey soil might be controlled by the thickness of the diffuse double layer (DDL) which governs the liquid limit. Sridharan and Venkatappa Rao (1979) stated that the liquid limit of soils is mainly influenced by the DDL held water.

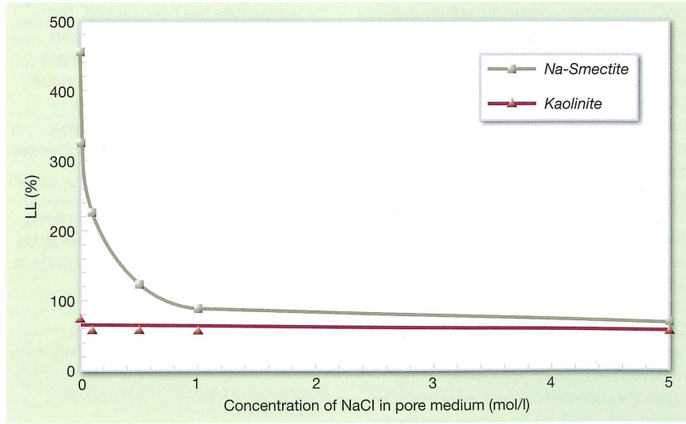
The most important conclusions concerning the structure of the double layer as function of the electrolyte concentration (and/or dielectric constant) of the fluid is that the extension of the double layer in solution decreases with increasing electrolyte concentration (or decreasing dielectric constant) as shown in the following equation (van Olphen 1963, Sridharan and Jayadeva 1982, Shang et al 1994, & Mitchell and Soga 2005):

$$\kappa^{-1} = \left(\frac{\varepsilon_0 \varepsilon R T}{2 n_0 e^2 \nu^2} \right)^{1/2}$$

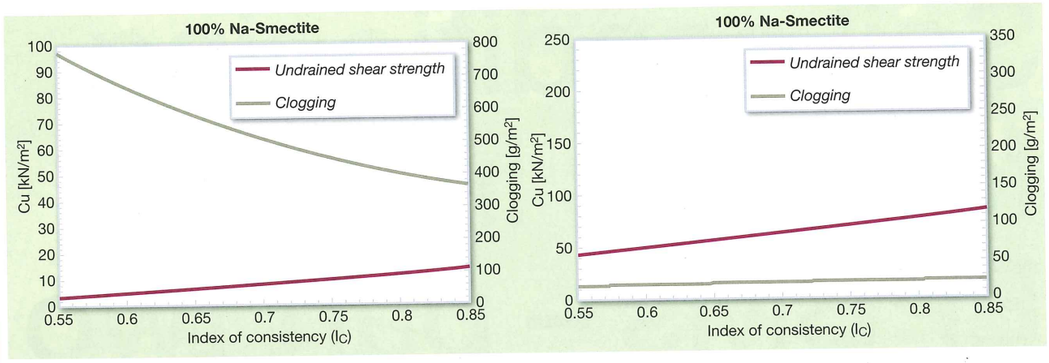
For kaolinite, a change in dielectric constant (or electrolyte concentration) does not lead to any noteworthy change in double layer thickness. It can be stated that the DDL for non-swelling clays is very small or non- existant. Hence, the DDL approach does not apply for such clays.

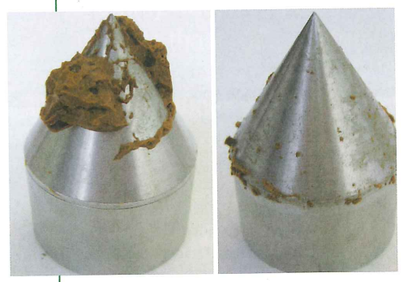
Figure 6 (below, left) shows the liquid limits for Na-smectite and kaolinite mixed with increasing concentrations of NaCl (common salt). It can be recognised that the influence of the double layer is very important for Na-smectite as an expansive clay. For this clay, a salt concentration of 1mol is sufficient to reduce the liquid limit to values close to the minimum. This behaviour corresponds with the data gathered by Di Maio (1996). For kaolinite no appreciable influence of NaCl on the liquid limit is observed.

Starting from these experimental results, the so called 'cone pull-out test' as a new laboratory test to determine the clogging behaviour of different fine-grained soils has been developed (Feinendegen et al 2010). In the relevant literature up to now most authors defined the stickiness of different fine-grained soils by a determination of the



Left: **Figure 6, variation of liquid limit for Na-smectite with increased electrolyte concentration in pore fluids**





Above, top: **Figure 8, Adherences to the test cone fpr water (left) and 1mol NaCl (right);** Above, bottom: **figure 9, Application of electro-osmosis to reduce clogging in laboratori on a pure smectitie**

adhesive forces. For this purpose mainly modified direct shear tests as well as separation tests, typically with steel pistons, have been carried out (Schlick 1989, Beretitsch 1992, Thewes 1999, Zimnik 2000, Burbaum 2009). However, one precondition for an exact measurement of adhesion forces is that there is no adherence of soil to the testing device. Particularly for piston pull tests this cannot be ensured. Furthermore, separation tests do not account for the influence of the soil parameters on the adherence.

Clogging only then occurs, when the resisting forces within the soil matrix are smaller than the bond stress between clay and steel surface.

The sample material is compacted in a standard proctor device; a steel cone is inserted into a pre-drilled cone shaped cavity and loaded for 10 minutes with the magnitude of the applied load between 3.8 kN/m² and 189 kN/m² depending on the consistency. The load is then taken off and the specimen is placed in a test stand where the cone is pulled out with a velocity of 5mm/min. The amount of soils attached to the cone is weighed and divided by the cone surface giving the "adherence" in g/m2 (Feinendegen et al 2010).

New manipulation

The cone pull-out tests were also used to determine the effectiveness of new manipulation techniques to reduce the adhesion and/or clogging of clays to the surfaces e.g. of a TBM. Since kaolinite did not show any variation in LL tests and since ethanol is not recommended for tunnelling projects, only smectite was tested mixed with water and NaCl as pore medium at different consistencies (i.e. 0.4-0.55-0.7-0.85) (figure 7, above). It gets clear how NaCl drastically reduces the adherences to the cone surface. This effect can also be seen in figure 8 (left, top). A possible explanation could be the suppression of the DDL, which causes a closer proximity of the clay particles. With a smaller DDL the clay structure becomes more compact and the amount of pore fluid necessary to induce particle mobilisation is reduced.

An alternative manipulation method may be the use of electro-osmosis. By applying an electric charge to the steel parts of a TBM, water is transported through the clay into the interface between clay and steel. This creates a film of water, the adherences are reduced, and the clay can easily be removed (van Baalen et al 2000). Using again the cone pull-out test, smectite was tested with water by applying a low electric

Above: **Figure 7, cone pull-out test (after Feinendegen et al 2010);**

field between the cone as negative pole (cathode) and the proctor mould as positive pole (anode).

After the application of a direct current (2.5V) for 10 minutes the cone was pulled out. The results show a strong decrease of material attached to the cone after this simple treatment (figure 9, left, bottom).

Electro-osmosis could be easily used in situ, however because of several collateral effects (e.g. corrosion of metallic parts, energy consumption, health and safety, probable disturbance of the TBMs computers) its use in a TBM should be tested on a real scale.

Conclusions

Based on theoretical and experimental works several chemical manipulations of clays were performed. Coupling the modifications obtained in laboratory with the cone pull-out test as a new laboratory test to determine the clogging propensity of different fine-grained soils, a decrease of the adherences has been proved. The variations of the pore fluids lead to an increase in their internal shear strength causing a drop of adhesion to the metal surface of the cone.

However, the pore fluid has a major influence on smectitic clays rather than on kaolinitic clays. Additionally, the applicability of electro-osmosis as alternative way of manipulation has been shown. The laboratory findings have to be applied in situ on real tunnelling projects in further investigations.

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10th International Symp on Tunnel Construction and Underground Structures, Ljubljana, Slovenia
Organised by the Slovenian Society for Underground Structures and the University of Ljubljana at Congress Center MONS. Topics include ground research, architectural features, construction, materials and safety. There will also be an excursion. Contact Tina Marolt, tel.: +386 1 470 46 24, email tina.marolt@ntf.uni-lj.si or see www.ita-slovenia.si

6 - 8 DECEMBER 2011
STUVA Conference, Berlin
The 2011 biannual conference of non-profit research institute STUVA (the German Research Association for Underground Transportation Facilities) will focus on 'Underground Construction for Sustainable Environmental and Climate Protection.' 1500 visitors from more than 30 countries are expected. New this year is a Youth Forum, an opportunity for young tunnel engineers to present. The winner of the STUVA young talent prize will be selected from the speakers, and awarded at the show. More information available from www.stuva.de Email: info@stuva.de

12 - 13 JANUARY 2012
Shotcrete 2012 (Spritzbeton-Tagung), Tyrol, Austria
Prof Wolfgang Kusterle and his team are hosting this conference and exhibition for shotcrete specialists. The conference will be in German with some presentation in English, and English summaries of all presentations will be available. The Final program will be available by October 17, 2011. For more information e-mail: spritzbeton@kusterle.net

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Fire Protection and Safety in Tunnels Asia, Singapore
With Asia having some of the longest tunnels in the world and some of the most rapid developments occurring globally this is the best platform to uncover current and future projects across the region and pinpoint the best strategies to ensure fire design is implemented accordingly. The conference will also include a site visit to a Singapore tunnel. More information is available at http://www.arena-international.com/fpstasia/

14-16 MARCH 2012
ISTSS 2012, New York, USA
Forum with the themes of risk and security, human behaviour, passive fire protection and construction, active fire protection & fire fighting, ventilation and fire dynamics. The focus is shifting more and more towards security, with new the terrorist threats and the focus on how to solve these problems increasing. Organised by SP Technical Research Institute of Sweden - Fire Technology. For more information see www.istss.se, email info@sp.se or tel.: +46 10-516 50 00

20-22 MARCH 2012
3rd Brazilian Congress on Tunnels & Underground Structures & Intl Seminar 'South American Tunnelling', Sao Paulo, Brazil
The event will include 11 topics and be run with an exhibition and technical visits. Two days will be reserved for a refresher course and training. Contact Executive Secretariat, Acqua Consultoria on tel.; +55 11 3868 0726, email 3cbt@acquacon.com.br or see www.acquacon.com.br/3cbt.

22-23 MARCH 2012
Intl Symp 'Practices & Trends for Financing & Contracting Tunnels & Underground Works', Royal Olympic Hotel, Athens, Greece
Organised by the Greek Tunnelling Society. ABSTRACT DEADLINE EXTENDED TO 15 NOVEMBER 2011. Contact GTS on tel.: +98-21-88630496, email bakojon@otenet.gr or see www.tunnelcontracts2012.com

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INTERtunnel 2012, Turin, Italy
Italy's only regular exhibition on tunnelling technology. For more information email: intertunnel@mackbrooks.com

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3rd Int Conf on Shaft Design & Construction, London, UK
Organised by the Mining Technology Division of the IMMM and the BTS at 1 Carlton House Terrace. The scope includes all areas of design and construction of both civil engineering project and mine shafts. Contact Paul Harris at IOM Communications by email paul.harris@iom3.org, tel. +44 (0)20 7451 7302 or see www.iom3.org/events/sdc2012.

18 - 23 MAY 2012
World Tunnel Congress WTC 2012 & 38th General Assembly of the ITA, Bangkok, Thailand
Organised by the Thailand Underground & Tunnelling Group (TUTG) of the Engineering Institute of Thailand with the ITA, the theme is 'Tunnelling & Underground Space for a Global Society.' For more information email: secretariat@wtc2012.com or visit www.wtc2012.com

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SSCS - Numerical Modelling, Strategies for Sustainable Concrete Structures, Aix-en-Provence, France
Organised by the Association Francaise de Genie Civil (AFGC). Contact Nadget Berrahou-Daoud on tel.: +33 1 44 58 24 29, email afgc@enpc.fr or see www.afgc.asso.fr

24 - 27 JUNE 2012
North American Tunneling Conference (NAT), Indianapolis, Indiana, USA
UCA's biannual conference, which has continued to grow each year with more exhibits, technical sessions & attendees. More information regarding housing and registration will be available at http://uca.smenet.org/ in spring 2012

18 - 21 SEPTEMBER 2012
Eastern European Tunnelling Congress, Budapest, Hungary
The Hungarian Tunnelling Association is organizing the 1st Eastern European Tunnelling Congress to share experiences and exchange knowledge of design, construction management, research results and technical developments of tunnels completed by the regional associations and experts. The planned regional sub European conference is open to all other co-organizers and participants as well as to those who having ongoing or completed projects, research works in this area. ABSTRACT SUBMISSION: 2 JANUARY 2012. More information at http://www.eetc2012budapest.com/

7 - 9 NOVEMBER 2012
13th World Conference of ACUUS, Singapore
The Associated research Centers for the Urban Underground Space (ACUUS) is presenting "Underground Space Development – Opportunities and Challenges." The intent is to focus on the new opportunities amid a re-focus on developing the urban underground space as part of sustainable development, and the many challenges and issues that planners, developers, and engineers face. More information at http://www.acuus2012.com

BRITISH TUNNELLING SOCIETY

17 NOVEMBER 2011:
Dulles Airport Rail Tunnel, Washington DC
Dulles Transit Partners is responsible for designing and constructing Phase 1 of the Dulles Corridor Metrorail Project. An 11.6 mile extension of the existing Washington Metro to Dulles International Airport. A central feature of the project is the Tysons Tunnel. The Tysons Tunnel is a twin-bore, two-track tunnel running at 762m in length between portals. The central 534m is being constructed by SCL. Speakers: Dominic Cerulli and Frank Jenkins of (Bechtel) Dulles Transit Partners and Vojtech Gall of Gall Zeidler Consultants

28-29 NOVEMBER 2011:
BTS Health & Safety Course 2011
At the Institution of Civil Engineers, London. Fees are GBP 90 to BTS members and GBP 130 to non-members. Registrations forms are available on www.britishtunnelling.org.uk to be sent to pauline.arundel@ice.org.uk.

15 DECEMBER 2011:
Cleaner Seas for Sussex
In order to treat the 95 million litres of wastewater generated each day by residents a new wastewater treatment works and 11km of new sewer were required. Now substantially complete find out how more than 11km of 1.8m and 2.4m diameter tunnels and associated shafts and pumping stations were completed.
Speakers: Ben Green, Southern Water programme manager and Craig Reade, Costain project manager

A DATE TO REMEMBER...

If you know of a tunnelling related conference, event, seminar or exhibition that is not listed here, we would be delighted to hear from you. Please contact the editor by post, email, fax or through our web site: Editor, 'Tunnels & Tunnelling International', Boundary House, 91-93 Charterhouse Street, London, EC1M 6HR, United Kingdom.
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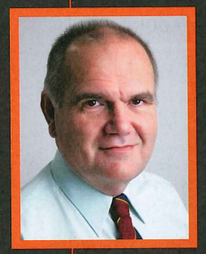

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